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Quiet Short-Haul Research Airplane (QSRA) Mode Select Panel Functional Description

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TABLE OF CONTENTS

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SUMMARY

The planned operation of the mode select panel and flight mode annunciator for the digital flight control system to be installed in the Quiet Short-Haul Research Airplane (QSRA) is described. The QSRA, when equipped with programmable color cathode ray tube displays, a head-up display, a general purpose digital computer and a microwave landing system receiver, will provide a capability to do handling qualities studies and terminal area operating systems experiments as well as to enhance an experimenter's ability to obtain repeatable aircraft performance data. The operating systems experiments include the capability to generate minimum fuel approach and departure paths and to conduct precision approaches to a STOLport runway. The mode select panel is designed to provide both the flexibility needed for a variety of flight test experiments and the minimum workload operation required by pilots flying into congested terminal traffic areas.

Acknowledgments

Although only one author appears on the cover, this report should be regarded as a compilation of ideas from a number of engineers and pilots at the Ames Research Center. The author was responsible for the layout of the QSRA instrument panel to accommodate two pilot operation in the style of modern airliners, the mode select panel and the flight mode annunciator to provide for a wide variety of flight experiments as well as to provide the pilots with an ATC oriented system which always deals with route, altitude

and speed. To Ames Research Pilot, Gordon H. Hardy, who has been the project pilot for the STOLAND digital flight control system from the inception of the program through the Convair CV-340, the Augmentor Wing Jet STOL Research Aircraft and the Twin Otter flight tests, goes the credit for helping the author formulate this report through frequent discussion and several careful reviews. To Dr. Heinz Erzberger must go the credit for creating the team that carried the onboard computer synthesis algorithms from theory to practicality and by so doing has created the tool needed to fly powered lift STOL airplanes efficiently. To Charles S. Hynes must go the credit for many fruitful discussions regarding EADI and HUD displays, the safety margin concept and a wealth of practical ideas on how airplanes are and ought to be flown. Dr. James A. Franklin is the creator of the stability and command augmentation system concept based on the methodology developed by Dr. George Meyer and Luigi Cicolani. To Bill Hindson, a pilot and engineer who was assigned to the Ames Research Center from the Canadian National Aeronautical Establishment for the latter years of the Augmentor Wing flight test program, goes the credit for devising a practical flight director system to allow the pilot to fly the powered lift STOL airplane along curved descending approach paths to a 30 m (100 ft) decision height.

INTRODUCTION

The flight research conducted to date on the Quiet Short-Haul Research Airplane (QSRA) has consisted of proof of concept testing, evaluation of performance, evaluation of handling qualities and providing operating experience with an upper-surface-blowing-flap powered-lift STOL airplane for STOLport and aircraft carrier operations (References 1 through 3). The research capability of the highly productive QSRA is presently being expanded to permit investigation of handling qualities and operating systems applications for this powered lift airplane. Equipment additions to the airplane consist of programmable, color electronic attitude director indicators (EADI), a headup display, an automatic power-lever, a terminal area navigation capability and a flight control digital computer to permit the development and evaluation of flight director laws, display formats, stability and command augmentation system (SCAS) control laws and energy management guidance and control laws. Since the major emphasis in the QSRA operating systems experiments program is on the use of a powered-lift airplane in the terminal area, the selection task for all of the elements listed above must require only a very small portion of the pilot's work-load. A mode select panel (MSP) and a flight mode annunciator (FMA) have been designed which incorporate the pilot assist modes found in recent conventional jet transports along with new selection features for a microwave landing system (MLS) and for a minimum fuel energy management guidance system. This report describes the operational features of all the modes incorporated into the mode select panel and the flight mode annunciator.

Recent jet transport design practice has been to place selectors for attitude stabilization, autopilot, autothrottle, flight directors, and speed/Mach altitude, rate of climb and heading pilot assist modes and dual VOR/ILS frequency and course selection in the glare shield area of the cockpit as shown in references 4 through 6. The QSRA MSP follows this pattern for engaging the flight director, attitude SAS servos, flap servos, auto-power-lever servos and speed, altitude, flight path angle and heading pilot assist modes. Although no pitch, roll and yaw autopilot capability is presently planned for the QSRA, the MSP contains provision for adding an autopilot at some later date. The QSRA glare shield panel area differs in several ways from the conventional jet transport pattern. Specifically, the QSRA relys on navigation from TACAN, MLS and INS but is not equipped with an automatic tuning navigation system common in the industry today. Instead, the QSRA navigation system is designed to provide precision navigation over a limited region to meet the specific needs of the experimenters. In the QSRA, a single course selector capability is incorporated into the MSP. All frequency selection has been relegated to the center console between the pilots. Because the MLS glideslope can be set to values other than the conventional ILS three degree glideslope, provision exists in the QSRA MSP for selecting the glideslope angle. The QSRA guidance and control system incorporates an area navigation system. In conventional jet transports, the area navigation system is operated through a keyboard and CRT display typically located in the center console since the pilots generally do not use area navigation in the terminal area except as a means of transitioning to the ILS along commonly flown and preprogrammed routes. Certainly, it is the rare pilot who will choose to introduce waypoint changes into the area navigation system when the airplane is operating in the terminal area. The guidance system planned for the QSRA is specifically designed to be used in the terminal area by synthesizing fuel efficient or time constrained paths which can be established to ease the pilot's and ATC controller's workload. The area navigation system in the QSRA provides for four pre-stored flight paths, each of which can incorporate up to 29 waypoints. A waypoint selector is therefore considered an important feature of the QSRA mode select panel. A number of experimental modes can be selected in the QSRA system and buttons for activating these modes are incorporated into the MSP. Since this is an experimental system, the QSRA MSP also incorporates spare buttons for potential future experiments.

The QSRA FMA continues the pattern found in current jet transports of annunciating modes to the pilot as an aid to his comprehension of how the airplane control system is operating. In the past, several different approaches have been taken. In the first approach, labels on an annunciator instrument are lighted to indicate the mode in operation and the modes which are armed. This has been satisfactory for conventional jet transports operating with a limited number of modes associated with VOR/DME and ILS but is inflexible for the needs of the QSRA experiments program. A second approach is to place the annunciator light in the mode selection button. This procedure has the disadvantage that the annunciation is not located near the pilot's scan region. There is also a tendency for an annunciator light located in a glareshield panel to wash out in sunlight. A third approach, which is becoming common in the industry and which was adopted for the QSRA, is to annunciate the modes on a FMA located just above the pilot's attitude indicator. By making the FMA programmable, a variety of modes can be incorporated and new modes can be added or deleted as required in a developing experiments program. The disadvantage of this type of FMA is that the pilot must read the symbols to understand the message rather than simply note the presence of a message in a location.

The compilation of MSP and FMA procedures and responses contained in this report is intended to serve three purposes. First, this document provides the basis for establishing agreement among the NASA experimenters and pilots as to how the QSRA flight director and SCAS systems should function. Second, the report provides a procedures reference for simulator and flight acceptance tests. Finally, this report is an instruction manual for future users of the QSRA system.

The discussion begins with a statement of design philosophy. Then the QSRA capabilities as a research airplane operating in the terminal area are reviewed and the experiments presently planned for the airplane are outlined. The MSP and FMA layout and the displays and controls selected by the MSP are described. An overview of the cockpit layout is presented. Then the attitude, flightpath and speed SCAS and the flight director systems are described. The remainder of this document is devoted to detailing the response of the MSP, FMA, displays and the airplane controls to pilot operation of the MSP selectors.

DESIGN PHILOSOPHY

Several guidelines have been adopted for developing the QSRA mode select panel and flight mode annunciator operating procedures.

1. No changes will take place in the reference values or in the switching of modes unless the pilot has made either a direct or indirect selection. An example of a direct selection is a reference window setting on the MSP which will not change value unless the pilot has dialed a new number. An example of an indirect selection is a guidance mode which either reads a number from memory or causes a new number to be computed. In both examples, the pilot has initiated action to change the window setting.

2. An action will always take place in response to the button push. The system will acknowledge a legitimate button push through a FMA indication. The system will respond to an incorrect button push by failing to engage the mode selected and by displaying an error message.

3. The QSRA system, in general, deals with three modes at all times: a

speed mode, a vertical mode and a lateral mode. The pilot will be responsible for engaging each mode separately under the guideline that the system will not respond unless the pilot specifically chooses to engage the mode. This is contrary to current air transport practice in which a master button typically engages all modes associated with the button function.

AIRPLANE AND PLANNED EXPERIMENTS

Airplane

The Quiet Short-Haul Research Airplane (QSRA) is an advanced propulsive-lift research airplane being used by NASA for a variety of flight research programs. Its mission is to generate data for use by the United States aerospace industry and various government agencies in the specification, design and certification of future propulsive-lift aircraft and their related systems.

The QSRA, shown in Figure 1a and described in Reference 7, employs the hybrid upper surface (USB) concept for propulsive lift. In this concept, the exhaust from four high-bypass-ratio turbo-fan engines mounted above the wing is directed over the upper surface of the wing and the flap system shown in Figure 1b. The exhaust "turning" together with bleed air boundary layer control (BLC) on the ailerons provides the lift augmentation. Other features of the QSRA include: double slotted flaps outboard of the USB flaps as shown in Figure 1c, spoilers for roll control and direct lift control as shown in Figure 1c, and ailerons that droop with flap deployment as shown in Figure 1d . The airplane was designed for two man flight crew operation.

The QSRA is essentially a conventional jet transport except for takeoff and landing when, through the deployment of the powered-lift flap system, the airplane has the capability of operating from a STOLport at speeds near 70 knots. The airplane is equipped with generally conventional controls as shown in Figure 2. The column operates the hydraulically powered elevator through both a mechanical cable and a force sensor to the electromechanical hydraulic actuator. The wheel provides roll control through a cable bell-crank connection to an aileron hydraulic actuator and also provides an electrical force sensor input to the SAS computer which in turn commands the actuators for both the aileron and spoiler panels. Directional control is from the pedals to the rudder actuator with an additional input from a lateral-directional SAS system. Four thrust levers are located to the left and forward portion of the overhead console between the pilot and copilot. A speed brake lever to the right of the power levers provides the pilot input to the spoiler computer. The spoiler computer also drives the spoilers for both direct lift control and roll control. The outboard double slotted flaps are selected by a lever located aft and to the right in the overhead console. The first 30^{0} of the USB deployment is selected with a lever aft of the power-levers. USB deployment from 30^{0} to 66^{0} is accomplished with a beep switch located on the left side of the #1 engine power-lever for the pilot and on the right side of the #4 engine power-lever for the copilot. If the USB flaps are deployed beyond 30^{0} and the pilot moves the USB flap handle out of the 30^{0} detent, the USB flaps will retract to the flap handle setting without further pilot application of the beep switch. The pilot controls roll and pitch trim through a coolie hat switch on the control wheel. The rudder trim switch is located on the case of the pilot's head-up display. In the event of an engine failure, the pilot can reduce the rolling moment using the flap discrete trim switch located on the windshield centerpost. The switch retracts one outboard flap to the 30^{0} position to reduce the rolling moment if USB and outboard flaps are extended beyond 30^{0}. A separate switch is located on the #1 power-lever to permit the pilot to initiate go-around guidance without removing his hand from the power-lever.

Navigation System

The current Air Traffic Control (ATC) system is based on VORTAC navigation for enroute operation and the instrument landing system (ILS) for the precision approach. Low altitude airways, high altitude jet routes and area navigation are all founded on the VORTAC system. Current area navigation systems often incorporate automatic tuning and position determination using dual DME or inertial navigation information.

The flight test work being conducted with the QSRA is primarily centered in a terminal area near the Crows Landing Navy Auxiliary Landing Field (NALF) near Modesto, California. Crows Landing NALF is equipped with a TACAN navigation transmitter and a microwave landing system (MLS). The airplane is equipped with a LTN-51 inertial navigation system to provide the steady reference needed to ensure that the head-up display images will register properly relative to the actual runway when the airplane is on the approach. The QSRA is flown from its home base at Moffett Field, California, to the Crows Landing NALF and will therefore be equipped to handle enroute navigation as well as precision navigation in the test site terminal area.

The requirement for satisfactory navigation enroute and precision navigation in the terminal area combined with the availability of precision velocity determination from the INS and the unavailability of an automatic tuning VORTAC navigation system provided the motivation to do navigation with a Kalman filter navigator design which was already developed and flight tested in a MLS equipped Twin Otter (Reference 8). It should be emphasized that the development and testing of the Kalman filter is not a QSRA research objective. Rather the choice of the Kalman filter was based on the availability of already developed software combined with a need for a precision navigation procedure which could accommodate a variety of navigation source inputs. Navigation sources presently planned are TACAN azimuth and DME; VOR azimuth and DME; MLS azimuth, elevation and DME; velocity measurements from a LTN-51 inertial navigation system as well as localizer and glideslope error from a standard ILS. Because of lack of automatic tuning of the VORTAC system, the QSRA pilots will have to assume responsibility for both selecting the frequencies in the VOR and TACAN navigation receivers and entering station identifier mnemonics in the onboard computer to properly establish the aircraft position in the computer coordinate system. The mode select panel, to be described in detail in a later section of this report, incoporates a button for initiating the Kalman filter either at a known location such as a surveyed parking spot on the airport ramp or in the air through the use of information from navigation receivers. The MSP also has buttons for enabling or rejecting data from the TACAN, VOR-DME, MLS or ILS. These buttons permit the pilot to disable a navigation data source as an input to the Kalman filter while he changes navaid frequency and stores the new navaid location in the computer.

The Air Traffic Control Operating Environment

The MSP and FMA for the QSRA have been configured to enable the pilot to readily interact with the present ATC system as well as to deal with the advanced ATC concepts involving area navigation and minimum fuel energy management approach paths.

In the present day ATC system, all clearances are issued in terms of a route to fly, an altitude assignment and at times, a speed restriction. The route to be flown is typically made up of radials into and out of navigation transmitter stations in the VORTAC system or designated waypoints while the airplane is enroute. The ATC controller typically issues radar vectors in the vicinity of the airport or, while the airplane is enroute, to avoid conflicting traffic. With the advent of area navigation systems now commonly in service, the route can be direct from point to point instead of navaid to navaid. Altitude assignments are in the form of instructions to maintain altitude, climb or descend to an altitude or cross a fix at an assigned altitude. Speed restrictions are either the result of the general regulation requiring the airspeed to be at or below 250 knots at altitudes below 3048 m (10,000 ft) or else are assigned by the ATC controller to maintain separation between airplanes.

Proposed future ATC system concepts are expected to deal with the speed, altitude and route components as an integrated trajectory. Such trajectories will probably be activated by separate buttons on the MSP but because of the ever present potential requirement for traffic avoidance radar vectors, the MSP must permit the pilot to revert to any combination of route, altitude and speed that may be assigned. Two examples of integrated trajectories are described below.

The 4D area navigation system described in Reference 9 was designed to compute an intercept path to and guide the aircraft along a prespecified flight path to an approach gate at a time specified by the ATC controller. Reference 10 describes a fuel-conservative automatic terminal-area guidance system having two modes of operation. In the first, or predictive mode, fuel-efficient approach trajectories are synthesized in real time using an on-board digital computer. In the second, or tracking mode, the synthesized trajectories are reconstructed and tracked automatically.

The techniques described in Reference 10 will be adapted to the QSRA to determine the synthesized minimum fuel trajectory. The synthesis trajectory will then serve as the reference for a flight director used either with or without a SCAS to enable the pilot to fly the QSRA along the minimum fuel path. Figure 3 shows how the energy management synthesis concept works. The on-board computation procedure for determining this minimum fuel path is described in Reference 11 and is briefly outlined here. The first part of the procedure is to compute the minimum distance horizontal path which begins at the aircraft's present position and heading and ends at the location and heading of a prestored reference flight path waypoint that has been selected by the pilot. The elements of the minimum fuel horizontal track are a circle through the aircraft present position with radius determined on the basis of the present aircraft ground speed and a design bank angle near 20^{0}, a second circle passing through the waypoint selected by the pilot from the waypoints on a prestored reference flight path and the tangent line connecting the two circles. The length of the track from the aircraft's present position to a final waypoint, typically located on the final precision approach path to the STOLport runway, is the sum of the length of the synthesized path to the intercept waypoint and the distance from that waypoint to the final waypoint. When the path length, the altitude difference between the present position and the final waypoint and the speed restrictions are known, an energy rate performance model derived from the airplane lift, drag and propulsion system characteristics is used in a synthesis algorithm to determine the optimized altitude-speed trajectory to the final waypoint. The exact path will depend on the wind and temperature profiles encountered during each landing approach. The general strategy used is to delay the descent as long as possible throughout the approach consistent with the requirements to slow the airplane to achieve a small radius turn and to keep the speed below the flap placard restrictions. All of the above requirements apply equally well to both conventional aircraft and powered-lift STOL aircraft in the cruise configuration. For powered-lift aircraft on an approach, an additional minimum speed restriction exists. Since a portion of the overall wing lift is induced by engine thrust, there is a minimum engine RPM that will still provide adequate lift to meet a safety requirement. This engine RPM minimum is a function of flap setting and must be included in the path-speed synthesis problem. Typically the goal will be to stabilize the airplane at a final approach speed simultaneously with reaching the final waypoint.

The mode select panel must be designed to help the pilot in the task of operating in the ATC environment and therefore must be configured to let the pilot vary speed, altitude and direction independently. The MSP must also permit the pilot to rapidly select the complex trajectories that are likely to appear in the future ATC system.

Planned Experiments

The powered-lift technology program includes research in flight dynamics as well as guidance and control systems for both military and civil short field operations. This program will provide the data base for flying qualities design, approach and landing criteria and landing field length contributions for powered lift aircraft conducting military and civil operations. The program also includes guidance concepts that provide fuel efficient and noise minimum operation of powered-lift aircraft. Both ground based simulation and substantial flight research on the QSRA will provide experimental results that will comprise the criteria data base.

The technical objectives are:

a) Determine the influence of advanced powered-lift control modes and display concepts on flying qualities throughout the terminal operating area.

b) Define approach and landing operating criteria for advanced controls and displays used for military and civil STOL operations.

c) Determine contributions to the landing distance for the STOL flare and landing.

d) Establish functional and performance requirements for fuel efficient guidance and navigation systems, air traffic control interface requirements, terminal area operating procedures into an airport equipped with a MLS system and the inter-relationships between the aircraft and pilot for several levels of powered-lift control modes.

e) Establish the control techniques and performance characteristics for go-around of powered-lift STOL aircraft.

COCKPIT DESCRIPTION

General Layout

The QSRA cockpit arrangement is shown in Figure 4. Both the pilot and copilot are provided with flight mode annunciators, color EADI displays and horizontal situation displays. The mode select panel is centered for use by both the pilot and copilot. A head-up display is provided for the pilot only. The black and white multi-function (MFD) display is located to the right of the pilot's EADI where it is viewable by both pilots. Each of the pilots has a column and control wheel which provides a standard cable drive to the elevator and aileron power control units as well as electrical force signals to the onboard digital computer to drive the attitude SAS. The auto-power-lever servo select switch is located along with the side-arm electric-power-lever select switch on the eyebrow panel above the copilot. USB and spoiler drives are armed through the flight control panel on the center console.

The cockpit arrangement will permit the development of two-pilot operating procedures for the powered-lift STOL airplane such as are now used by some airlines for flying Category II approaches. In such a procedure, the copilot flies the approach using his head down flight director and raw data displays. Throughout the approach, there is challenge and response dialogue between the pilot and copilot. The pilot monitors the approach and is responsible for acquiring the runway visually at or before decision height and then for taking control of the airplane to complete the landing. If the pilot does not take command of the airplane before it reaches the decision height, the copilot flies the missed approach procedure.

Although it will be possible to develop and evaluate the two-pilot procedures for the QSRA, the system does not have the redundancy that would be required for airline operation because the pilot and copilot EADIs are driven by a common symbol generator. In order to provide an emergency backup capability for instrument meteorological conditions (IMC) in the event of failure of the digital flight control system, a minimum set of backup IFR instruments is installed in the copilot's panel.

Electronic Attitude Director Indicator

The QSRA digital avionics EADI/HUD symbol generator contains three display options. The first option is the pitch attitude centered display format that was used for the Augmentor Wing EADI. The second option is the flight path oriented display format which will be described below. The third option is a simplified version of the second option for use on the HUD. The second option will be used for the purpose of discussing the operation of the Mode Select Panel and the Flight Mode Annunciator.

Figure 5 depicts the flight path oriented display format appropriate to area navigation reference flight path tracking when the runway is in sight. In the background are the roll attitude scale marks ( ) at the top of the EADI and the pitch attitude marks ( ) throughout the display. The roll attitude cursor is the symbol ( ) and pitch attitude cursor is the symbol ( ). The USB flap configuration is indicated by the flap symbol below the wings of the pitch attitude symbol ( ). The heading tape (080 100) appears on the horizon along with the heading reference symbol (Δ).

Calibrated airspeed is shown as a digital readout in the upper left corner of the EADI. Radio altitude is displayed digitally in the upper right corner provided the airplane is below 762 m (2500 ft) above ground level. The advisory message indicator is shown in the upper center of EADI. A red rectangle and the symbol W is displayed on the EADI and a W is displayed on the HUD to direct the pilot's attention to the FMA status panel warning message. An amber rectangle and the symbol, C, is displayed on the EADI and the symbol, C, is displayed on the HUD to alert the pilot to the presence of a caution message on the FMA status panel. The pilot cancels warning and caution messages by pressing the FMA lighted message warning light. The path deviation box shows the position error from a reference path generated from MLS center line and glideslope or by a reference flight path stored in computer memory. A perspective runway is shown in the center of Figure 5. The line at the beginning of the perspective runway is the runway threshold. The 61 m (200 ft) touchdown zone markers are shown beginning 91 m (300 ft) from the threshold.

The center of the circle of the flight path angle symbol ( ) shows the tip of the airplane velocity vector. The vertical displacement of the symbol is based on an estimated sinkrate and estimated groundspeed provided navigation is available and on estimated sinkrate and airspeed if navigation is not available. The sinkrate estimate is based on radio altitude when the airplane is near touchdown, MLS derived altitude when the airplane is in MLS coverage and barometric altitude otherwise. The lateral displacement of the symbol is based on the availability of the sideslip angle determined from INS or MLS. If neither INS nor MLS is available, the flight path angle symbol is a single solid line ( ).

The speed error from the reference speed is displayed on the left wing of the flight path angle symbol ( ). The power-lever director is displayed on the right wing of the flight path symbol ( ).

The top segments of the dashed line symbol (‾_‾ ‾_‾ ‾_‾ ‾_‾) show the reference glideslope angle and the lower segments show the downward flight path angle capability when the airplane is within the MLS arm region. Normally, the reference glideslope will be -6^{0} and the downward flight path capability will be -9^{0}.

The vertical scale on the left side of the EADI display and the associated symbols provide safety margin information. The top of the scale represents 150% safety margin, the center mark represents 100% and the bottom mark represents 50% safety margin. A value of 0% represents the safety margin boundary and is not displayed. The current safety margin status is indicated by the diamond symbol (◇) and the commanded safety margin is designated by the half diamond symbol (>).

Two different pitch and lateral flight director symbology formats were considered for the EADI and HUD. The first of these consists of separate, disconnected bars that cross when the airplane is tracking the flight director reference; one for lateral mode direction and one for vertical mode direction. The advantage of this format is that the bars are completely independent; when all lateral modes are off, the lateral mode bar simply disappears and when all vertical modes are off, the vertical mode bar disappears. The pilot is never presented a nonfunctioning director display. The disadvantage of this format is the tendency of the two bars to obscure other display elements near the center of the EADI and HUD displays.

The second flight director format consists of double arrow segments ( ) which translate up and down ( ) to provide a pitch director and rotates ( ) to provide a roll or lateral director. When both lateral and vertical flight director commands are nulled, the flight director symbol is lined up on the tip of the wings of the flight path angle symbol ( ) The double arrow format has the advantage that it leaves the center of the display uncluttered with director symbology. The disadvantage of the double arrow display is that the pilot may conclude that both vertical and lateral flight director commands are being provided when in fact one of the two commands may be inactive. With the advent of the color EADI display, a means exists to indicate to the pilot that part of the flight director symbology is not providing a command. The color code adopted here is that when both lateral and vertical command modes are active, the double arrows are colored pink. If only a lateral command mode is active, the double arrows are colored yellow and if only the vertical mode is active, the arrows are colored white. The pilot is probably not going to remember the meaning of the yellow or white colors but when he sees a change from pink, he can quickly refer to the FMA to determine which mode is active and which is not.

Because of the reduced clutter, the double arrow flight director is adopted for the QSRA and it is this format of flight director symbology that appears in Figure 5.

Still another type of symbology may be used as an aid to the pilot for flying a MLS precision approach. This is called the ghost airplane and appears on the EADI/HUD as a cross centered on a circle ( ). When used, the ghost airplane symbol replaces the flight director symbology. The ghost airplane perfectly flies the MLS centerline and glideslope reference ahead of the actual airplane. The pilot task is to center the tip of the airplane velocity vector on the ghost airplane in which case the ghost airplane and the flight path angle symbol become concentric ( ). The pilot can determine that the airplane is within the acceptable approach tolerance if the wings of the ghost airplane intersect the runway centerline.

The ghost airplane symbology described above will typically be used only for the MLS final approach. The two cue flight director symbology combined with the path deviation box can be used for flying both MLS approaches and reference flight paths and will therefore be used in the description of the MSP operations which follow.

Multifunction Display

Figure 6 shows the black and white Multifunction Display (MFD) that is installed in the QSRA. Across the top of the MFD is a heading tape showing 90^{o} of the 360^{o} compass rose. The reference heading bug shows the MSP setting selected by the pilot. The magnetic heading is shown in the top center window if the map is displayed course up. The top center window shows course if the map is in heading up. The output of the time code generator is at the top to the right. Estimated mean sea level (msl) altitude appears at the top to the left. The estimated msl altitude is derived from radio altitude beginning when the airplane is determined to be over the STOLport runway during a precision approach, from MLS azimuth, elevation and DME beginning when the airplane is in MLS coverage and from the barometric altimeter otherwise. Smooth transitions are made from barometric altitude to MLS altitude, from MLS altitude to radio altitude and, at go around, from the current altitude reference back to barometric altitude. The reversion to barometric altitude is completed by the time the airplane has climbed through an altitude increment of 122 m (400 ft).

Navigation annunciation information is displayed just below the heading tape. The first column lists the sources of navigation information; INS when the LTN-51 inertial navigation system is selected and SDN when the strapdown vertical gyros are selected, MLS for microwave landing system, TAC for TACAN and VOR for very high frequency omni range or ILS for instrument landing system. These navigation source mnemonics are displayed at low intensity if the navaid is selected at the MSP and are blank if the navaid is not selected at the MSP.

INS appears in the top row if the INS is selected at the MSP. Normally the INS sensor output signals are inputs to the Kalman filter. If INS is not selected, the vertical gyro strapdown sensors will be used as inputs to the Kalman filter and SDN will appear on the MFD navigation annunciator.

The latitude and longitude estimated position coordinates appear in the top row of navigation annunciation following INS or SDN. The pilot enters latitude and longitude coordinates prior to taxi and the navigation system estimator updates the coordinates during taxi or flight. The Kalman filter must have navigation sensor inputs to maintain an accurate aircraft position estimate. If navigation sensor information is interrupted or if the computer is powered down, the Kalman filter estimate of position is no longer valid. Even without valid navigation information available, the Kalman filter continues to estimate the aircraft position based on INS if INS is available or on the strapdown vertical gyros and air data information if the INS is not available. The dead reckoning begins with the loss of navaid signals and is annunciated by DR followed by the number of minutes since dead reckoning has begun as shown to the right on the top line of navigation annunciation. Dead reckoning with INS information will provide a good position estimate for extended periods of time but dead reckoning position based on strapdown information is probably not reliable after a few minutes of elapsed time.

Azimuth, DME and elevation columns are provided for MLS, TACAN and VOR/ILS. Entries in the TAC or VOR/ILS columns show the station mnemonic for the navaids which are used to establish the aircraft position on the MFD map. Station identifier mnemonics appears in any column where a signal element is expected to exist. It is a pilot task to both enter the station identifier mnemonic at the keyboard to locate the navaid properly in the computer coordinate system and to tune the corresponding navaid frequency in the navigation receiver heads. TACAN and VOR provide azimuth and DME information as shown in Figure 6. An ILS typically provides localizer and glideslope information but not DME. Some ILS systems in the United States also include a co-located DME but none of the ILS systems in the area where the QSRA will operate have co-located DMEs. Examples of station identifier mnemonics are TNUQ for the Moffett Field TACAN, VSJC for the San Jose VOR and ISJC for the San Jose Runway 30 Left ILS. The station identifier mnemonics can appear blinking (off-low intensity-off ....) or as low intensity solid letters or as high intensity solid letters. A blinking station identifier indicates which navaid location is stored in the computer and that the signal from the station is not valid. A low intensity solid identifier mnemonic means that the signal is valid but not used as an input to the Kalman filter. A high intensity solid identifier mnemonic means the signal is both valid and used as an input to the Kalman filter.

Since only one MLS station exists in the QSRA operating area, a station identifier is not used. Instead, the azimuth, DME and elevation signals appear at low intensity if the signal is valid but not used as an input to the Kalman filter and at high intensity if the signals were used in the last cycle of the Kalman filter computation. If any signal is not valid, the corresponding space will be blank.

Map display features available on the MFD are shown in Figure 6. Airport symbols including runway numbers are provided. Terrain obstruction symbols are shown as a pictorial mountain and an associated altitude. The aircraft symbol not only locates the airplane relative to the map features but also indicates the state of the Kalman filter. If the Kalman filter is not activated, the last coordinates in the computer locate a lenticular aircraft position symbol. If the Kalman filter is activated but not yet converged, the aircraft position symbol is an isoceles triangle which blinks on and off. If the Kalman filter is converged, the aircraft triangle symbol is solid at high intensity. When dead reckoning begins, the aircraft triangle symbol pulses from high to low intensity. The map can appear at three scales: 0.5 NM/inch, 1.5 NM/inch or 5 NM/inch. These scales are selectable at the multifunction display control panel (MFDCP). The map can be oriented course up, heading up or north up. When in heading up, the vector ahead of the airplane symbol shows the course. When the map is oriented course up, the vector ahead of the airplane symbol indicates the heading. A two segment trend vector also appears ahead of the airplane. The tips of the two segments indicate where the airplane will be pointed in 20 seconds and 40 seconds based on airplane bank angle. The previous track of the airplane is shown with the history dots.

The MFD displays one of the four prestored reference flight paths that can be selected at the MFDCP. Waypoints are designated by the four pointed star symbols and an associated number. The waypoint towards which the airplane is headed is designated to the left of the MFD along with the altitude of the waypoint and the time to the waypoint.

Horizontal Situation Indicator

Horizontal Situation Indicator (HSI) is a conventional electromechanical instrument display which has been modified for use with the QSRA digital flight control system. An annotated view of the HSI is shown in Figure 7. Operation of the HSI, which is summarized below, is adapted to the QSRA from the STOLAND Augmentor Wing Operators manual, Reference 12.

Heading

The heading card continuously indicates airplane heading as derived from the existing compass system on the aircraft. The heading warning flag will be in view if the heading information is invalid.

Heading Select Pointer

This pointer indicates the heading selected by the pilot at the MSP and always reads the same as the digital heading select readout on the MSP. When the flight director modes are initially engaged, or when HDG HOLD is selected, the heading select pointer and MSP heading select dislay will initialize at the existing heading.

Course Select Pointer

This pointer indicates the course selected by the pilot at the MSP and always reads the same as the digital course select readout on the MSP. In the AREA NAV mode, the course select pointer moves automatically to continuously indicate the course of the reference flight path at any instant.

BRG Pointer 1 and DME Window 1

a) VOR selected on HSI Switch No. 1

BRG Pointer 1 will show VOR bearing if valid. If not valid, the bearing pointer will be parked at north. DME window 1 will show DME range if it is valid and if VOR is on at the MSP. Otherwise, the DME shutter will be closed.

b) MLS Selected on HSI Switch No. 1

BRG Pointer 1 will show MLS bearing (azimuth angle) if valid. If not valid, the bearing pointer will be parked at north. DME Window 1 will show MLS range if valid and if VOR is not on at the MSP. Otherwise, the shutter will be closed.

BRG Pointer 2 and DME Window 2

a) TAC Selected on HSI Switch No. 2

BRG Pointer 2 will show TAC bearing if it is valid. If it is not valid, the bearing pointer will be parked at north. DME Window 2 will show TAC range if it is valid. If TAC range is not valid, the shutter will be closed.

b) WPT Selected on HSI Switch No. 2

BRG Pointer 2 shows bearing to the next waypoint if AREA NAV is on at the MSP. Otherwise, the bearing pointer will be parked at north. DME Window 2 shows the distance along the reference flight path to the next waypoint if AREA NAV is on at the MSP. Otherwise, the shutter will be closed.

To/From Indicator

The To/From Indicator is biased out of view when no navaids are selected at the MSP. When a navaid is selected, it operates in the conventional manner. It indicates TO (arrow in same direction as course select pointer) if the angle between the course select pointer and the bearing pointer for the navaid in use is less than 90 degrees. It indicates FROM (arrow in opposite direction to course select pointer) if this angle is greater than 90 degrees.

Course and Vertical Deviation Indicators (CDI and VDI)

a) If AREA NAV is on at the MSP and the pilot has selected the point at which he wishes to enter a reference flight path, the CDI will show lateral deviation from the flight path. When the Flight Director captures the lateral flight path, the Vertical Deviation Indicator (VDI) will show deviation from the vertical path. The scalings are 152 m (500 ft) per dot for lateral deviation and 15 m (50 ft) per dot for vertical deviation.

b) If TAC or VOR is on and AREA NAV is off at the MSP, the CDI will show angular deviations from the radial selected at the MSP and displayed by the HSI course pointer. The VDI will be out of view. The scaling is the same as on a standard VOR or TAC CDI, approximately $\pm$ 10 degrees full scale ($\pm$ 2 dots).

c) If ILS or MLS is on and AREA NAV is off at the MSP, the CDI will indicate localizer deviation from the runway course selected at the MSP. The VDI will indicate glideslope deviation.

d) In the ILS mode the CDI and VDI have standard scalings of approximately $\pm$ 2 degrees full scale ($\pm$ 150 μA = $\pm$ 2 dots) for the localizer and approximately $\pm$ 0.7 degree full scale ($\pm$ 150 μA = $\pm$ 2 dots) for the glideslope.

In the MLS mode, the CDI is scaled the same as for ILS localizer ($\pm$ 2 degrees full scale). The VDI sensitivity is decreased linearly as the glideslope reference angle is steepened. At any altitude on the glideslope, this causes the VDI deviation to represent the same altitude error from the glideslope as it would with a standard ILS glideslope, independent of the glideslope reference angle in use. If a glideslope reference of -2.8 degrees has been selected at the Keyboard, the VDI has the same sensitivity as for an ILS glideslope. If the glideslope reference is -6 degrees, the VDI corresponds to $\pm$ 1.5 degrees of glideslope deviation full scale.

Course Deviation and Vertical Deviation Warning Flags

In the AREA NAV mode, the course and vertical deviation warning flags are biased out of view. In any other mode, the warning flags are keyed to the selector switches on the HSI. If the course deviation is invalid for both selected bearings, the course deviation warning flag will be in view. If the course deviation is valid for either selected bearing, the course deviation warning flag will be out of view.

The vertical deviation is keyed to selector switch 1 (MLS or VOR/ILS). If the selected signal's vertical deviation is valid, the vertical deviation warning flags will be biased out of view.

Mode Select Panel and Flight Mode Annunciator Layout

The layout of the Mode Select Panel (MSP) and Flight Mode Annunciator (FMA) is shown in Figure 8. The MSP incorporates relay held toggle switches for engaging series attitude SAS servos, a power-lever servo, flap drive servos and spoiler servos; push button switches for engaging a flight director, a head-up display, a variety of speed, altitude and route modes and a navigation system; liquid crystal reference windows and selectors for speed, altitude and route; and a lighted display dimming potentiometer. The FMA incorporates four character liquid crystal displays to annunciate arm and couple speed, vertical and lateral modes, a sixteen character message panel and an acknowledge button.

The MSP is partitioned into four sections. At the top of the left section of the MSP are an ATTITUDE relay held toggle switch which engages pitch, roll, and yaw series SAS servos; a LIFT/DRAG relay held toggle switch which engages the auto-power-lever, USB flap drive and spoiler drive; a lighted pushbutton which engages the flight director display on the EADI and HUD, a lighted STBY ON switch which initializes mode logic, a lighted HUD selector switch, a spare switch which is reserved for future use to couple mode logic to autopilot parallel servos (not presently installed) and a rheostat for display night lighting. The pilot assist section contains selector knobs for setting speed, flight path angle, altitude and heading reference windows and push buttons for selecting flight reference select and hold, speed select and hold, flight path angle select and hold, altitude select and hold and heading select and hold. The guidance section contains selector knobs for setting the glideslope, course and waypoint reference windows and push buttons for activating TACAN, VOR/ILS, MLS and AREA NAV modes. A trajectory generator (TRAJ GEN) button activates the onboard computer algorithms for calculating minimum fuel trajectories. LAT NAV activates lateral guidance, VERT NAV activates vertical guidance, SPD PROF activates stored or computed speed guidance and SPD CONF establishes a speed reference as a function of the USB flap setting. The navigation section contains a lighted NAV START button for initiating convergence of the Kalman navigation filter and buttons for enabling TACAN, VOR/ILS, MLS or INS as navigation sources for the Kalman filter. The fastest rate of change of the reference setting is obtained by pushing and rotating the setting knob.

FLIGHT CONTROL SYSTEM EXPERIMENT MODES

THE QSRA flight control system consists of pitch, roll and yaw SCAS; a lateral flight director; a vertical and speed flight director and vertical and speed SCAS. Five vertical and speed modes are planned for the QSRA: a flight director mode, designated Mode 0 (meaning that all vertical and speed SCAS modes are off), which is used in conjunction with pitch, roll and yaw attitude SCAS and manual manipulation of power-levers, flaps and spoilers; a manual mode, designated Mode M, which is the same as Mode 0 except that the pilot uses a single electric power-lever for thrust control; a frontside mode, designated Mode F, which provides a pitch flight director with the SCAS driving the electric power-lever, USB flaps and spoiler servos; a cruise mode, designated Mode C, which provides a pitch flight director with the SCAS providing thrust control; and finally, a backside mode, designated Mode B, which provides both flight director and SCAS commands to the USB and spoiler servos.

The terms frontside and backside refer to the frontside and backside of the airplane power required curve. In the context used here, a frontside control technique means that flight path corrections are most effectively made with the control column/elevator and speed corrections are made with power-lever. This is the control technique commonly used for flying a jet transport both in high speed cruise and during an ILS approach. When an airplane slows to speeds below the minimum drag speed, i.e., the speed for which the sum of induced drag and parasite drag is a minimum, the effectiveness of the controls changes. During cruise, the powered-lift STOL airplane is effectively a jet transport and therefore is a frontside airplane. But at low approach speeds, the powered-lift STOL airplane operates on the backside of the power required curve. Reference 11 shows that for such backside operation, the most effective control for changing flight path is the power-lever to adjust thrust level and the most effective control of speed is the control column/elevator.

The discussion of the SCAS and flight director modes begins with the pitch attitude SCAS.

Pitch Stability and Command Augmentation System

The QSRA has two separate pitch stability and command augmentation system (SCAS) options. The first of these is the system that was installed when the airplane was built and is turned on through a center console panel. This system will not be used in combination with the flight path-speed SCAS, but may be engaged at the pilot's discretion for use with the flight director system to be described later.

The SCAS uses control laws which are described below and is activated with the ATTITUDE switch on the MSP. An engineering block diagram of the pitch rate-attitude hold system, adapted from the Augmentor Wing Jet STOL Research Airplane (AWJSRA), is shown in Figure 9. This is the system that will be engaged any time the flight path-speed SCAS is engaged (i.e., any time the LIFT/DRAG switch on the MSP is engaged).

As shown in Figure 9, attitude stablization is accomplished through attitude feedback used to provide suitable closed loop stability. Rate commands are generated in the feed-forward paths in response to column force from a wheel hub mounted electrical transducer. A feed-forward signal is supplied for forces above $\pm$ 8.9 N (2.0 lb) provided the wheel force does not exceed $\pm$ 186.8 N (42 lb) for more than 1.5 seconds to cause a disconnect. Gain scheduling, as a function of dynamic pressure, maintains a relatively constant total loop gain over the aircraft's flight envelope; gain scheduling of the column force command, as an inverse function of airspeed, maintains a relatively constant relationship of column force to normal load factor over the envelope. With the attitude switch selected and the column force less than $\pm$ 8.9 N (2.0 lb), an automatic trim system offloads the pitch series servo. When the ATTITUDE switch on the MSP is engaged, the pilot's coolie-hat trim button on the wheel is disabled. A more complete description of the pitch rate-attitude hold system as it applied to the Augmentor Wing airplane is contained in Reference 14.

The LIFT/DRAG and ATTITUDE switches on the MSP are interlocked so that if both switches are engaged and the ATTITUDE switch drops, due to an attitude SCAS disconnect, the LIFT/DRAG switch will also disconnect. This procedure avoids the situation where speed or path stabilization is attempted without adequate inner loop attitude stabilization being available. On the other hand, failure of some part of the SCAS system, which is activated with the LIFT/DRAG switch, does not create a hazardous condition and consequently dropping the LIFT/DRAG switch does not drop the ATTITUDE switch.

Roll and Yaw Stability and Command Augmentation System

Lateral-directional stabilization and command augmentation are provided by a SCAS concept that includes roll rate-command-bank-angle-hold in the lateral axis in combination with Dutch-roll mode augmentation and sideslip suppression in the yaw axis. Block diagrams of this SCAS concept are shown in Figures 10 and 11. For the roll SCAS (Figure 10) bank-angle stabilization is accomplished through the roll-attitude feedback and roll-rate feedback is used to augment closed-loop stabililty. Roll-rate command is generated in the integral feed-forward path in response to wheel position. The use of a wheel force command input was rejected since the lateral control feel system force detent was insufficient to isolate the pilot's control wheel from force feedback from the lateral SAS actuator. The yaw SAS is shown in Figure 11. In this system, lateral acceleration feedback increases the frequency of the Dutch-roll mode and feedback of washed-out yaw rate and bank angle increases the damping ratio of this mode. Turn coordination is provided by bank-angle feedback in the steady state. Yaw SAS authority is $\pm 10^{0}$ of rudder for this system. The system described above is taken intact from the Augmentor Wing airplane. The system description is reported in Reference 14.

The roll and yaw SCAS system is engaged, along with the pitch SCAS, through the ATTITUDE relay held switch on the MSP.

Lateral Flight Director

The QSRA lateral flight director operates like a conventional flight director for a CTOL jet transport. Two different formats can be programmed for the QSRA EADI: a vertical bar which moves right or left in the EADI display (|) or a format consisting of two arrows directed to the center of the display which rotate to provide a command (⇨ ⇦). Since the MSP logic normally presents both a roll and pitch mode when the flight director is turned on, the second format is adopted for all flight director functional descriptions which follow. Regardless of which format is used, the pilot must maneuver the airplane to null the director and in so doing, the airplane assumes the correct roll attitude to track the reference.

A block diagram of the flight director system appears in Figure 12. This is the same system that was employed for the Augmentor Wing airplane: the diagram is taken from Reference 15. Command guidance signals, in the form of lateral position error and lateral rate error are generated for six lateral reference modes that can be selected at the MSP: heading hold (HDG HOLD) or select (HDG SEL), TACAN course (TAC), VOR course (VOR), ILS localizer, MLS centerline, or stored and computed area navigation track (AREA NAV). To avoid abrupt bank angle overshoot maneuvers, a turn prediction term is used to lead heading changes. In addition, inner loop stabilization is provided through bank angle and roll rate feedback terms.

Mode 0 - Flight Director Only

The most general of the flight path-speed flight director laws to be flown on the QSRA is shown as a block diagram in Figure 13 and is designated Mode 0 meaning the SCAS is turned off. The left side of Figure 13 shows the references that the pilot establishes with the MSP selector knobs and reference windows and then selects with the push button switches. Figure 13 also shows the feedforward gains from the references to the blending coefficients, the blending coefficients C_1 through C_4, the feedbacks and associated gains, the limiters and the command bar drive signals.

There are four possible speed references which are generally labeled V_{sel} in Figure 13. These are flight reference hold (FR HOLD) or select (FR SEL), speed hold (SPD HOLD) or select (SPD SEL), a speed profile (SPD PROF) either stored in computer memory or computed in association with area navigation and speed configuration (SPD CONF) where the speed reference is a function of flap setting. There are five possible flight path and altitude references which are designated THTCOM in Figure 13. These are: flight path angle hold (FPA HOLD) or select (FPA SEL), altitude hold (ALT HOLD) or select (ALT SEL), instrument landing system glideslope (ILS), microwave landing system glideslope (MLS) and a vertical profile associated with an area navigation route which may either be stored in computer memory or determined onboard as part of an energy management synthesis computation and which is activated with the VERT NAV button.

The pitch flight indicator bar ( ) is driven vertically by a speed reference through a blending coefficient, C_1, and is summed with a flight path reference through another blending coefficient, C_2, along with pitch and pitch rate inner loop feedback signals. The blending coefficients vary from 0 to 1 as a function of outboard flap and USB flap settings. When the airplane is in the flaps up configuration, it behaves, as noted earlier, like a CTOL transport operating on the frontside of the power curve. In this case, the path reference alone drives the pitch flight director bar because C_2 is unity and C_1 is zero. When both the outboard flaps and the USB flaps are fully extended, the airplane is fully converted to backside operation where speed control is accomplished through the elevator controlling pitch. In this case, C_1 is unity and C_2 is zero. During the transitition from frontside to backside, both blending coefficients are non-zero and the pitch flight director bar is driven with a linear combination of speed and path references.

Similarly, the power-lever director, the bar which emerges from the right wing of the velocity vector symbol ( ), is driven through the C_3 and C_4 blending coefficients as a linear combination of speed and path references. When operating frontside, the power-lever flight director bar is driven by the speed reference. When operating backside, the power-lever flight director bar is driven by the path reference.

The pitch flight director bar is driven not only by the speed and path references through the C_1 and C_2 blending coefficients, but is also always driven in response to pitch and pitch rate feedback terms for stability. The power-lever bar is driven by both speed and path commands through the blending coefficients C_3 and C_4 as well as a combination of engine RPM and power-lever position feedback through washout transfer functions.

Limiters are placed on the drive signals to both the pitch flight director bar and the power-lever director bar. Two limiting conditions are imposed. Pitch attitude command is not to exceed $\pm$ 15 degrees and the pitch bar will not command a flight path angle greater than $\pm$ 5 degrees away from the current reference path. The philosophy for limiting the flight director bar is based on the work described in Reference 15.

Mode M - Manual - Electric Power Lever

Figure 14 is a block diagram of the flight director system and electric-power-lever system when Mode M is engaged. The pilot controls engine RPM using a single handle located convenient to his right hand. When in operation, the electric-power-lever handle provides an electrical command signal to the power-lever servo. When not in use, the handle and its mounting arm swings back out of the way.

The block diagram at the bottom of Figure 14 describes the electric-power-lever system. Commanded thrust from the power-lever proportional sensor, Mach number, the atmospheric temperature ratio (Θ_2) and the atmospheric pressure ratio (δ_{AMB}) are entries to a computer stored table from which is read an estimate of desired stage 2 RPM, N_2. This estimated RPM is converted to a power-lever position command through a stored schedule of RPM versus N_2. Estimated RPM is then differenced with the trim position of power-lever derived through the RPM to N_2 schedule as applied to measured N_2. The difference between power-lever handle position commanded from N_2 command and handle position derived from actual RPM is passed through a gain and summed with the command power-lever position to form the command for the servo inner loop. Average power-lever handle position, $\delta_{T_{AVE}}$, and power-lever handle rate feedbacks are summed with the command for the servo inner loop to form a drive signal for the servo which in turn drives the four control cables to the engine fuel controls.

The Mode M pitch flight director bar is driven just as for Mode 0. The power-lever director command signals are also the same as for Mode 0. However, the signal into washout 2 comes from the electric-power-lever command rather than from the power-lever handle position pickoff.

Mode F - Frontside Path/Speed

The engineering block diagram for Mode F, the frontside mode, is shown in Figure 15. This mode provides flightpath-airspeed stabilization and control augmentation from outboard flap deployment through the STOL approach. The frontside mode utilizes USB flaps, DLC spoilers and power-levers to provide flightpath command, airspeed stabilization and thrust command. The frontside mode requires outboard flaps to be deployed and airspeeds to be below about 120 knots. The system operates conceptually by generating commands for the appropriate controls that will produce acceleration in the longitudinal and vertical axes as required to achieve the command flightpath angle and airspeed. The control commands are computed by solving the non-linear multivariable aerodynamic expressions that relate accelerations (or aerodynamic coefficients) to control positions.

Figure 15 shows the flightpath and airspeed command structure for the frontside mode. This structure accepts command inputs from the pitch attitude SAS (θ_c) and from the MSP airspeed reference (V_{SEL}) and combines these inputs with complementary filtered vertical velocity ($\dot{h}_c$), calibrated and true airspeed (V_c and V_T), bank angle, thrust command and computed gross weight to derive lift and drag coefficients ($C_{L_{SCAS}}$ and $C_{D_{SCAS}}$) for inputs to the appropriate control modes.

The frontside flightpath SCAS uses the $C_{L_{SCAS}}$ and $C_{D_{SCAS}}$ inputs as well as commanded angle of attack (α_c) to compute USB flap and thrust commands from tabular relationships. Commanded angle of attack is derived as shown in Figure 15 from commanded pitch attitude and computed flightpath angle. An angle of attack bias is included that can be driven manually from the pitch trim bias (θ_T) or computed elsewhere in the control program. The thrust command also provides an input to the DLC spoilers through a washout filter. Spoiler bias is determined by USB flap position. The flight director associated with the frontside mode, shown at the top of Figure 15, uses flight path angle or altitude commands from the MSP selected vertical mode functions along with pitch attitude and pitch rate feedback to drive the pitch flight director bar. Since the augmented airplane effectively flies as a frontside vehicle at all times, there is no need to introduce the blending coefficients. Power-lever servo error is displayed to the pilot with the bar symbol located on the right wing of the aircraft velocity vector symbol.

Mode C - Cruise Path/Speed

The engineering block diagram for the cruise mode is shown in Figure 16. The auto-power-lever logic shown in the lower half of Figure 16 provides speed stabilization during cruise flight. The auto-power-lever mode drives the power-lever to stabilize the aircraft during flaps-up cruise flight above the outboard flap placard speed of 120 knots. This system operates conceptually by generating commands for the power-lever system that will produce acceleration in the longitudinal axis as required to achieve the commanded airspeed. As described for the frontside mode, the power-lever servo command is computed by solving the non-linear multivariable aerodynamic expression that relates acceleration to control position. Since thrust control is required, a thrust command system is provided to drive the power-lever servo system.

A comparison of Figures 15 and 16 shows that the method of generating the desired drag coefficient ($C_{D_{SCAS}}$) is the same for the cruise mode as for the frontside mode. The cruise flight auto-power-lever logic defines thrust commands from $C_{D_{SCAS}}$, α_C, outboard flap (δ_{FC}) and calibrated airspeed (V_C) inputs. A tabular relationship between these variables is used to solve for the thrust command. The thrust command system accepts an input from the airspeed SCAS computation ($T_{G_{SCAS}}$) and processes this signal to drive the cables to the four engine fuel controls as described for Mode M.

The flight director block diagrams for the cruise and frontside modes are identical.

Mode B - Backside Path/Speed

The engineering block diagram for Mode B, the backside mode, is shown in Figure 17. This mode provides speed stabilization during the approach using USB flaps after both the outboard flaps and the USB flaps have been deployed to initiate the approach.

This system operates conceptually by generating commands for the appropriate controls that will produce accelerations in the longitudinal axes as required to achieve the airspeed. As for both the frontside and cruise modes, the control commands are computed by solving the non-linear multivariable aerodynamic expressions that relate accelerations (or aerodynamic coefficients) to control positions. The aerodynamic relationships are in tabular form as a function of several variables. The backside airspeed stability augmentation system computes USB flap commands based on $C_{D_{SCAS}}$ and C_T inputs. Figure 17 shows that a pitch command from the column force sensor is summed with a nominal flight path angle, γ_{ANOM}, which is set by the pilot at the MSP. The sum is then resolved into the stability axis where it is added to filtered and integrated velocity error, scaled and finally summed with mass flow rate to generate the demand drag coefficient, $C_{D_{SCAS}}$. This demand drag coefficient is one entry to the tabular relationship which generates the USB flap (δ_{USB}) command. The nominal gross thrust is scaled to provide the other entry to the table. The command to the USB servo is formed as the table output ($\delta_{USB_{CMD}}$) minus the USB setting established by the pilot through the cockpit USB selector and power-lever mounted beep switch. Deployment of the USB's produces both lift and drag changes. To obtain a pure drag force requires that the lift component be canceled and this is accomplished by a USB to spoiler crossfeed through a washout. Also driving the spoilers are a direct lift control input ($\delta_{SP_{DLC}}$) and a washed out average throttle handle position. The upper portion of Figure 17 shows the flight director for the backside mode. The control law driving the pitch flight director bar is the same as for the Mode 0 flight director. The blending coefficients are retained to help the pilot transition onto the glideslope in the backside mode. The power-lever director is driven only as if the airplane is operating backside. Thus the gain, k_{THTBS}, is the same as if C_3 were zero and C_4 were unity.

Path-Speed Mode Selection

Figure 18 is a computer flow chart of the logic for selection of the logic for selection of the path-speed modes. The logic paths provide either an all-modes-off condition or one of the five modes previously described. In some cases, only part of the conditions for establishing a mode may be met. In such cases, a message is provided to the pilot to alert him that the setup is incomplete.

MODE SELECT PANEL AND FLIGHT MODE ANNUNICATOR OPERATION

Organization of MSP Procedures

The remainder of the report is devoted to step by step operating procedures for the MSP and FMA in terms of action taken by the pilot and response from the system. The start-up procedure is presented first and then followed by the pilot assist modes and the guidance modes.

Start-Up Procedure

Power Up

Action	System Response
Power-up at the circuit breaker panel	The EADI displays the airplane symbol, the horizon and associated heading tape, the heading reference symbol for the heading last set at the MSP, the pitch and roll scales, the radio altitude, the flap status symbol and the airspeed. For airspeeds below 30 knots, the airspeed registers 30 knots.
	The pilot will select either the vertical (strapdown) gyros or INS attitude indications as the source of attitude information for the EADI and HUD. The selector is located adjacent to the pilot's EADI as shown in Figure 5.

The MSP windows show the reference values previously stored in the computer. These reference windows can be reset by the pilot using the selector knobs on the MSP. All windows in the FMA will be blank.

The MFDCP lighted buttons indicate the map selection and scale that were last in computer memory. The MFD displays the previously stored map selection (MFD 1 or MFD 2 or MFD 3), location, orientation and scale; the navigation annunciation information; the altitude; the heading tape; heading reference symbol; course or heading in the center window depending on whether heading-up or course-up is selected at the MFDCP time code; and selected reference flight path. The aircraft position stored in computer memory is displayed with a lenticular symbol if navigation has not been started or an isoceles triangle if the Kalman filter navigation is active.

Navigation

Prior to pushing NAV START, the pilot must select station identifier mnemonics through the keyboard, tune the navigation receivers and either activate the INS or choose to use the vertical gyros in place of INS. The pilot will be able to determine the navigation status from the annunciation data available on the MFD. There are two start modes: a ground start is initiated if the airplane nose gear squat switch is closed and an air start is initiated if the nose gear squat switch is open. The ground start will be assumed to take place on either the Ames Research Center ramp or near the Crows Landing NALF refueling area. A local TACAN navigation aid will be established through a tuned channel and an associated computer location mnemonic. When the pilot selects TNU, the status panel will display TNUQ =

C123, the latitude and longitude coordinates of the Moffett Field TACAN will be stored for use in determining navigation geometry and the initial INS latitude and longitude survey point coordinates for the Ames Research Center ramp will be stored. The pilot must enter increments parallel and perpendicular to the runway to locate the airplane relative to the ramp latitude and longitude survey point. A similar procedure will be used at Crows Landing where the INS reference point is by the refueling pit. The navigation station identifier mnemonic is entered as TNR and read on the status panel as TNRC = 39. The Crows Landing TACAN latitude and longitude are stored in memory. With both navaid and INS available, a bias correction to the TACAN signal can be estimated to improve position determination during the subsequent flight.

The air start mode will only be initiated if the pilot perceives that a gross error has developed in the Kalman filter navigator. Pushing the NAV START button when the airplane is airborne will cause the Kalman filter to begin convergence based on position data from the best navigation source available: first MLS, then TACAN or, finally, VOR.

Action	System Response
Push NAV START to ON	The START portion of the NAV START switch lights and the TAC, VOR/ILS, MLS and INS buttons are enabled independent of the STBY switch state. The navigation system Kalman filter convergence begins if the INS is active or if a navaid and the strapdown sensors are active. The isoceles triangle symbol appears on the MFD and blinks on and off to show that filter convergence is in progress. When INS is used, the Kalman filter employs all valid navigation signals to estimate aircraft position and, if the airplane is at a known ground location, can compare known latitude and longitude position information with the navaid

derived position to establish the navaid bias for future use. Convergence can take place using only INS if no navaids are valid. If the strapdown gyros are used, MLS or TACAN or VOR/DME must be valid for convergence to begin. At the end of a convergence time period of 60 seconds or when a velocity change is detected, the Kalman filter switches into the navigate mode and provides a continuous estimate of aircraft position. The aircraft isoceles triangle symbol becomes solid at high intensity.

If the airplane is airborne, when the NAV START button is pushed, the starting location can be determined only from navaid inputs. Therefore, the starting location is not likely to be as accurately known for an air start as for a ground start where the initial location can be established from survey points.

Should all navigation inputs to the system become invalid, the Kalman filter provides a dead reckoning estimate of position using INS or strapdown sensor information. The pilot is advised of the beginning of dead reckoning by the caution message, DEAD RECKONING, on the FMA message panel. The MFD aircraft position symbol pulses from low to high intensity and the symbol DR is displayed along with the time in minutes since dead reckoning began. The pilot is free to make a judgment about the validity of the aircraft position estimate. The estimate can be trusted for a considerable period of time if it is based on INS data. But if the dead reckoning estimate is based on strapdown gyros, the position estimate is probably unreliable after two minutes. When a navigation input again becomes available, the Kalman filter estimates the aircraft position, the dead reckoning annunication on the MFD disappears and the aircraft position triangle becomes solid.

Push NAV START from ON to OFF	The NAV START button annunication light goes off and the MFD displays a lenticular aircraft symbol based on the last position estimate available.

Standby Switch

The standby (STBY-ON) switch provides a method for initiating and enabling flight director modes, SCAS modes, time constants, washouts and all MSP reference windows. All other functions are enabled when the power is turned on at the circuit breaker panel or when the NAV START button is pushed.

Action	System Response
Push STBY to ON	The ON portion of the STBY-ON switch lights and the MSP windows show engage values of the airplane state for SPEED, FPA, ALT, HDG and CRS. The G/S window shows the last stored value (nominally -6^{o}). WPT shows the last waypoint number stored in memory. The display elements of the EADI shown in Figure 5 that were not turned on with power initiation are now enabled and will appear as subsequent MSP modes are selected. Specifically, the flight path angle bar appears

if the navigation filter needed to establish a sinkrate estimate is converged. The flight path angle bar shows aerodynamic flight path angle if only airspeed is available or inertial flight path angle if either INS or MLS is available. The safety margin display elements, pitch, roll and speed director bars, the perspective runway, the path deviation bar, the glideslope reference and downward flight path angle capability are enabled.

Flight Director and Head-Up Display

Both the flight director and the head-up display are driven from the symbol generator as shown in Figure 19. The symbol generator has two software output formats: for a HUD and for the pilot and copilot EADI's. In a typical airline transport cockpit, the pilot and copilot displays are driven by independent sensors and command logic to provide control system redundancy. Separate switches are provided to turn on the pilot and copilot flight directors and these switches are typically labeled FD1 and FD2. The QSRA research system has only a single complement of sensors and a single computer so it is necessary to drive both EADI and HUD flight directors with the same format. The essential difference between the HUD and EADI formats is the number of display elements. The HUD has considerably fewer elements than the EADI. The same formats must appear on both of the EADI display units. Therefore, only a single switch, labeled FD1, is used to turn on the flight director.

Action	System Response
FD1 from OFF to ON	The MSP FD1 button shows ON. The engage values of heading and flight path angle appear in the MSP reference windows when the flight director switch is turned on. The EADI/HUD shows the heading reference symbol (Δ) on the horizon heading tape. The flight

director symbol ( ) appears pink on the EADI/HUD and is referenced to the MSP heading and flight path angles. For SCAS modes O, M and B, the flight path angle may also be the reference for the power-lever director bar located on the right wing of the velocity vector symbol ( ) if the USB flaps are extended. The FMA shows $\boxed{\text{FPA HDG}}$.
The power-lever director does not appear until the pilot selects a speed reference for frontside operation or a path reference for backside operation.

FD1 from ON to OFF

The MSP FD1 button light is off. All flight director functions are removed from the EADI/HUD.

HUD from OFF to ON

The MSP HUD annunciator light is ON. The aircraft symbology and attitude symbology appear and are driven from strapdown gyros or from INS attitude sensors depending on which is selected by the pilot. Symbology under software control appears on the HUD. For example, a flight director symbol will appear if and only if the flight director switch (FD1) is on.

HUD from ON to OFF

The MSP HUD button light is off. All display symbology is removed from the HUD.

Pilot Assist Modes

This section contains selection procedures and annunication for six pilot assist modes. The pilot assist modes consist of one lateral mode, heading hold and select (HDG HOLD & SEL); two vertical modes, flight path hold and select (FPA HOLD & SEL) and altitude hold and select (ALT HOLD & SEL); and three speed modes, speed hold and select (SPD HOLD & SEL), flight reference hold and select (FR HOLD & SEL) and speed configuration (SPD CONF).

Lateral Mode - Heading

As previously described, the heading hold flight director mode is automatically engaged when the FD1 button shown in Figure 8 is pushed. The heading hold mode described below is activated either by the FD1 button or by pilot selection of heading hold to replace one of the other lateral modes which may have previously been in operation.

Action	System Response
Push HDG HOLD to ON	The MSP HDG window shows the heading of the airplane when the HDG HOLD button was pushed. The EADI/HUD shows the heading reference symbol (Δ) on the horizon heading tape. The lateral flight director symbol ( ) is referenced to the MSP heading window setting. If both a lateral and vertical mode are active, the flight director symbol is colored pink. If only the lateral mode is active, the flight director symbol is colored yellow. The FMA shows HDG if only the lateral mode is active.
Push HDG HOLD from ON to OFF	The MSP HDG window does not change. The EADI/HUD bug (Δ) does not change. The lateral flight director symbol disappears if all vertical flight director references are off or becomes white and is oriented parallel to the airplane velocity vector

symbol ( ) if a vertical flight director mode is active. The lateral mode annunciation is deleted from the FMA.

Set the HDG and push HDG SEL (HDG HOLD is OFF)

The MSP HDG window shows the slew knob window setting. Upon pushing HDG SEL, the FMA shows $\boxed{\text{HDG}}$. The lateral flight director symbol ( ) on the EADI/HUD provides guidance command to the pilot. When the airplane is within 2 degrees of the window setting, the FMA shows $\boxed{\text{HDG}}$. The flight director symbol provides guidance to the MSP HDG window value. While in HDG SEL, the pilot may change the MSP window setting using the HDG knob. Guidance is then to the new window setting.

With HDG HOLD ON, set the HDG window and push HDG SEL

The MSP HDG window shows the slew switch setting. If the setting is different than the airplane heading, the window blinks until HDG HOLD is achieved. Upon pushing HDG SEL, the FMA shows $\boxed{\text{HDG}}$. The lateral flight director symbol ( ) on the EADI/HUD provides command to the pilot referenced to the MSP HDG window. When the airplane heading is within 2 degrees of the window setting, the FMA shows $\boxed{\text{HDG}}$.

With HDG HOLD ON set the HDG window

The FMA continues to show $\boxed{\text{HDG}}$. If the HDG window is different than the ex-existing reference value, the window will blink on and off. If the pilot pushes HDG HOLD OFF and ON, the MSP HDG window will become solid and will show the aircraft head-

	ing at the time the HDG button was pushed ON.
With HDG SEL active, push HDG HOLD	The FMA switches from HDG to HDG when HDG HOLD is pushed. The MSP HDG window stops blinking and shows the heading of the airplane when the HDG HOLD button was pushed. The EADI/HUD heading reference symbol (Δ) jumps to the window setting. The lateral mode flight director symbol is referenced to the MSP HDG window setting.
Push HDG SEL from ON to OFF	The MSP HDG window is solid at the airplane heading when the HDG SEL button was pushed. The EADI/HUD heading bug (Δ) moves to the MSP HDG window setting. The lateral flight director symbol ( ) is referenced to the MSP HDG window setting and the FMA shows HDG .

Vertical Modes - Flight Path Angle and Altitude

The flight path angle hold mode described below is activated either by the FD1 button on the MSP or by pilot selection of flight path angle hold to replace a previously active vertical mode. The flight path angle select and the altitude hold and select modes are only invoked by pilot selection. The flight director features activated by the vertical mode selection may appear on the pitch flight director or on the power-lever director depending on which of the possible flight director or SCAS modes is active and where appropriate, also depending on the USB flap setting. The system responses described below will cover all the possibilities of flight director and SCAS modes.

Action	System Response
Push FPA HOLD ON	The MSP FPA window shows the flight path angle

of the airplane when the FPA HOLD button was pushed. The EADI/HUD vertical flight director symbol ( ) provides guidance referenced to the FPA window setting for modes F and C. If modes O, M or B are active, the MSP FPA window provides the reference for the pitch or power-lever directors depending on the USB flap setting. The EADI pitch director symbol will be pink if a lateral mode is also active or white if only the vertical mode is active. The FMA shows $\boxed{\text{FPA}}$.

Push FPA HOLD from ON to OFF

The MSP FMA window does not change. The EADI/HUD vertical mode symbol will disappear for Modes C and F if no lateral mode is active or will rotate centered on the tip of the aircraft velocity vector (see Figure 5) if a lateral mode is active. In the latter case, the EADI lateral flight director symbol will be colored yellow. If modes O, M or B are active, the vertical reference for the pitch and power lever directors is eliminated but the pitch director symbol may remain active for speed guidance depending on the USB flap setting. If the pitch director is active for partially backside speed guidance, the power lever bar will also appear on the right wing of the aircraft velocity vector symbol. The vertical mode FMA windows are blank.

Set the FPA window and push FPA SEL (FPA HOLD is OFF)	The MSP FPA window shows the slew switch setting. Upon pushing FPA SEL, the FMA shows FPA. The EADI/HUD vertical flight director symbol ( ) provides guidance referenced to the FPA window setting for Modes F and C. If modes O, M or B are active, the MSP FPA window provides the reference for the pitch or power-lever directors depending on the USB flap setting. The EADI pitch director symbol will be pink if a lateral mode is active. When the airplane FPA is within 0.2^{o} of the selected angle, FPA SEL converts to FPA HOLD and the FMA shows FPA. While in the FPA SEL, the pilot may change the MSP window setting using the FPA knob. Guidance is then to the new window setting.
With FPA HOLD ON, set the FPA window and push FPA SEL	The MSP FPA window shows the slew knob setting. If the setting is different than the previous hold reference value, the MSP FPA window blinks on and off until FPA HOLD is again achieved. Upon pushing FPA SEL, the FMA shows FPA. The EADI/HUD vertical flight director symbol ( ) provides guidance referenced to the MSP FPA window setting for modes F and C. If modes O, M or B are active, the MSP FPA window provides the reference for the pitch or power-lever director depending on the USB flap setting. The EADI pitch director symbol will be pink if a lateral mode is also active or white if only the vertical mode is active. When the airplane FPA is within 0.2^{o} of the selected angle, FPA SEL reverts to FPA HOLD, the MSP FPA window stops blinking to become

	solid and the FMA shows $\boxed{\text{FPA}}$. While in the FPA SEL, the pilot may change the MSP window setting using the FPA knob. The flight director reference is then to the new window setting.
With FPA HOLD ON, set the FPA window	The FMA continues to show $\boxed{\text{FPA}}$. If the FPA window is different than the existing reference value, the window blinks on and off. If the pilot pushes FPA HOLD off and on, the MSP FPA window will be reset to the existing flight path angle and will become solid.
With FPA SEL active, push HOLD	The FMA switches from $\boxed{\text{FPA}}$ to $\boxed{\text{FPA}}$ when the FPA HOLD button is FPA pushed. The MSP FPA window stops blinking and shows the flight path angle of the airplane when the FPA HOLD button was pushed. The reference for the flight director symbology is the MSP FPA window setting.
Push FPA SEL from ON to OFF	The MSP window becomes solid at the airplane flight path angle when the FPA SEL button was pushed. FPA SEL is replaced by FPA HOLD and the EADI/HUD vertical mode flight director or the power-lever director are referenced to the MSP FPA window as appropriate to the flight director or SCAS mode set and where applicable, to the USB flap setting. The FMA shows $\boxed{\text{FPA}}$.
Push ALT HOLD ON	The MSP ALT window shows the altitude of the airplane when the ALT HOLD button was pushed. The EADI/HUD vertical mode flight director symbol ( ) provides guidance

referenced to the ALT window setting for modes F and C. If modes O, M or B are active, the MSP ALT window provides the reference for the pitch or power lever directors depending on the USB flap setting. The EADI pitch director symbol will be pink if a lateral mode is also active or white if only the vertical mode is active. The FMA shows $\boxed{\text{ALT}}$.

Push ALT HOLD from ON to OFF

The MSP window does not change. The EADI/HUD vertical mode flight director symbol will disappear for modes C and F if no lateral mode is active or will rotate centered on the tip of the aircraft velocity vector (see Figure 5) if a lateral mode is active. In the latter case, the EADI lateral mode flight director symbol will be colored yellow. If modes O, M or B are active, the vertical reference for the pitch and power lever directors is eliminated but the pitch director symbol may remain active for speed guidance depending on the USB flap setting. If the pitch flight director is active for partially backside speed guidance, the power lever bar will also appear on the right wing of the aircraft velocity vector symbol. The vertical mode FMA windows are blank.

Set the ALT window and push ALT SEL (ALT HOLD is OFF)

The MSP ALT windows shows the slew switch setting. Upon pushing ALT SEL, the FMA shows $\boxed{\text{ALT}}$. The EADI/HUD vertical flight director symbol ( ) provides guidance referenced to the ALT window setting for modes F and C. If modes O, M or are active, the MSP ALT window provides the reference for the pitch or power-lever directors depending on the USB flap setting. The EADI pitch director symbol will be pink if a lateral mode is also active or white if only the vertical mode is active. If the difference between the MSP window altitude and the aircraft present altitude is less than $\frac{1}{2}\frac{\dot{h}^2}{g_{REF}}$ where $\dot{h}$ is the rate of climb and g_{REF} is 0.68 m/sec^2 (2.25 ft/sec^2), the flight director symbology provides guidance for capturing the MSP reference altitude. If the absolute difference between the MSP reference altitude and the present altitude is less than 7.6 m (25 ft), the ALT HOLD mode replaces ALT SEL, the FMA shows $\boxed{\text{ALT}}$ and the vertical mode flight director symbology provides guidance to maintain altitude. If the difference between the MSP window setting and the present altitude is greater than $\frac{1}{2}\frac{\dot{h}^2}{g_{REF}}$, the FMA shows $\boxed{\text{ALT}}$ and the vertical mode flight director symbology remains in the previously active mode with two exceptions. First, the pilot may choose to fly the airplane into the altitude capture region without using the MSP flight path angle features. In this case, the flight director symbology will remain referenced to the previously selected mode until the airplane is near the MSP reference altitude. In the second exception, the pilot may choose to use the MSP flight path angle hold and select features, previously described to provide guidance to the altitude capture region. If the pilot establishes an altitude intercept flight path angle and pushes the FPA HOLD button, the FMA shows $\boxed{\text{ALT FPA}}$ and the flight director symbology guides to the MSP FPA reference window value. If the pilot dials the MSP FPA window setting and then pushes FPA SEL, the FMA vertical mode capture window alternates between ALT-FPA-ALT-FPA....until the altitude capture criterion is satisfied. Then the FMA shows $\boxed{\text{ALT FPA}}$ until the altitude capture criterion is satisfied at which point the FMA begins to display $\boxed{\text{ALT}}$. When the altitude error is less than 7.6 m (25 ft), the FMA shows $\boxed{\text{ALT}}$.

With ALT HOLD ON, set the ALT window

The FMA continues to show $\boxed{\text{ALT}}$. If the ALT window is different than the existing reference value, the window blinks on and off. If the pilot pushes ALT HOLD off and then back on, the MSP ALT window will be reset to the existing altitude and the window will become solid.

With ALT HOLD ON, set the Alt window and push ALT SEL

The MSP altitude window shows the slew switch setting. If the setting is different than the airplane altitude, the window blinks until ALT HOLD is again achieved. Upon pushing ALT SEL, the ALT HOLD mode is canceled and thereafter the operation is as described above for "Set the ALT window and push ALT SEL (ALT HOLD is OFF)."

With ALT SEL active, push ALT HOLD

The three possible FMA indications, $\boxed{\text{ALT}}$ or $\boxed{\text{ALT FPA}}$ or ALT-FPA-ALT-FPA...in the vertical mode arm position, prior to pushing ALT HOLD are canceled and replaced by $\boxed{\text{ALT}}$

when the the ALT HOLD button is pushed. The MSP ALT window stops blinking and shows the altitude of the airplane when the ALT HOLD button was pushed. The vertical mode flight director symbology appears and is referenced to the MSP ALT window setting.

Push ALT SEL from ON to OFF

The MSP window becomes, or remains, solid at the reference window setting when the ALT SEL button was pushed. The ALT SEL mode and possibly associated FPA SEL mode are canceled. The system reverts to a FPA HOLD mode and the EADI/HUD vertical mode flight director symbology is referenced to the MSP FPA window which is set to the FPA value existing when the ALT SEL button was pushed off. The FMA shows $\boxed{\text{FPA}}$.

<u>Speed Modes - Speed, Flight Reference and Speed Configuration</u>

Four possible speed references are available for the flight director symbology and three of these speed references are also used for the SCAS. The speed reference associated with area navigation and labeled SPD PROF will be discussed in a later section. The three speed modes that are regarded as pilot assist modes are labeled SPD for speed selected in knots, FR for flight reference selected in percent of a safety limit speed and SPD CONF for speed configuration where speed is a function of outboard and USB flap setting.

Two reference airspeed numbers are displayed to the pilot. The first number appears in the MSP speed window and may be set by the pilot. The MSP speed window may also be set by the computer as a function of flap setting using either stored data or computer generated data. The second number appears in the upper left window of the FMA and is the current reference speed for the flight director symbology or the SCAS. The two numbers can be the same provided the number in the MSP window can be achieved with the exisiting flap configuration and provided the aircraft speed has been constant long enough for the FMA speed window to slew to the MSP setting. For the SPD and FR modes, the pilot sets the MSP window value with the MSP speed selector and can even set speeds that exceed the flap placard when the flaps are down. The only restrictions are that MSP speed reference window will not accept speeds above the maximum operating airspeed, 160 knots, nor below the landing approach airspeed. The landing approach airspeed is calculated from aircraft gross weight, which is an input to the computer, and from the pilot selected landing USB flap setting. The pilot must enter the landing USB flap setting using the keyboard mnemonic LFP which stands for landing flap. The pilot establishes the landing approach airspeed in the MSP speed window by rotating the speed knob counterclockwise until the window value stops changing. If the MSP and FMA reference numbers are different, the number in the upper left window of the FMA smoothly progress toward the MSP speed window value at a rate of 1 kt/sec unless prevented from doing so by either a flap placard limit or a configuration dependent minimum safe speed limit for the current flap setting. Should a speed hold mode be engaged when the speed is greater than 160 knots, the MSP will jump to 160 knots and the FMA speed window will slew from the engage value to 160 knots at a rate of 1 kt/sec. If the speed mode is engaged when the speed is below the landing approach speed setting, the MSP window will jump to the landing approach speed value and the FMA speed window will slew from the engage value to the configuration dependent minimum safe speed limit, again at a rate of 1 kt/sec. Consider the following example. Suppose the landing approach airspeed value is 68 knots, the engage airspeed is 65 knots and the flaps are set so the minimum safe speed is 80 knots. The MSP speed window will jump to 68 knots when SPD HOLD is pushed. The FMA speed window will initially show the engage value to 65 knots but will slew to 80 knots in 15 seconds.

During an airspeed decrease, if the pilot does not lower the flaps before selecting a lower speed, a "LOWER FLAP" caution message will appear on the FMA message panel. Conversely, during an airspeed increase and if the pilot does not raise the flaps before selecting the higher speed, a "RAISE FLAP" caution message will appear on the FMA message panel. Once the flaps are repositioned as directed by the message, the caution message will disappear from the FMA message panel.

Regardless of which flight director or SCAS mode is engaged, the speed error, formed as the difference between the FMA reference speed and the calibrated airspeed, appears on the left wing of the aircraft velocity vector symbol ( ) shown in Figure 5. For modes F and C (Figures 15 and 16), the FMA speed reference for SPD or FR or SPD PROF provides the input to the SCAS. The power-lever servo error appears from the right wing of the aircraft velocity vector symbol ( ). For modes O and M (Figures 13 and 14), the FMA speed reference from SPD or FR or SPD PROF or SPD CONF is the input to the power-lever director on the right wing of the aircraft velocity vector symbol ( ) (Figure 5) for frontside operation. As the outboard and USB flaps are extended, the FMA speed reference drives both the pitch director ( ) and the power-lever director ( ) through the blending coefficients C_1 and C_3. Finally, with the flaps fully extended for backside operation, the FMA speed reference goes only to the pitch bar ( ). For mode B, the FMA speed reference SPD, FR and SPD PROF are inputs to the pitch flight director through the C_1 blending coefficient as shown in Figure 17. SPD and FR are inputs to the SCAS, also as shown in Figure 17.

Before describing the speed reference button pushing response in detail, further explanation of both the safety and the flight reference features is warranted.

The safety margin display on the EADI/HUD is intended to show the pilot the current and projected status of the airplane relative to minimum safe speed or angle of attack boundaries. This display, shown to the left side of the EADI in Figure 5, consists of three elements: a thermometer scale with the 100% mark in the center, a 150% mark at the top and a 50% mark at the bottom; a diamond symbol (◇) to indicate the current status of the airplane and a rotated chevron symbol (>) to indicate the pilot or computer selected desired target status. In terms familiar for a conventional airplane, the 100% mark would correspond to the traditional target approach airspeed of 1.3 V_{stall}. A 0% value would correspond to V_{stall}. For a powered-lift airplane such as the QSRA, the 0% value is a function of airspeed at normal approach power settings and angle of attack for very low power settings. If the pilot maintains a 100% safety margin, the airplane has a satisfactory combination of speed and angle of attack to overcome atmospheric disturbances during the approach. The three elements of the safety margin display appear on the EADI/HUD only when the airspeed exceeds 30 knots which is the minimum speed used for any of the control laws in the computer. This display is under keyboard control and can be removed from the EADI/HUD at the pilot's discretion by setting the mnemonic ESM to zero.

The flight reference feature of the MSP permits the pilot to establish a target safety margin at or above 100% by either flying the airplane to a desired safety margin percentage and pushing FR HOLD to ON or by setting a percentage greater than 100% in the MSP speed window and pushing FR SEL. When either FR HOLD or FR SEL is pushed, the speed director symbology is referenced to the present value of safety margin shown in the upper left window of the FMA. The speed director symbology is a combination of pitch and power-lever directors depending on which SCAS or flight director mode is selected and in the case of modes O, M or B, depending on the flap setting. The MSP and FMA operation of the SPD and FR speed modes is presented in detail below.

<u>Action</u>	<u>System Response</u>
Push SPD HOLD ON	The MSP speed window shows the airplane calibrated airspeed when the SPD HOLD button was pushed. The upper left window of the FMA shows the reference for the EADI/HUD speed error symbol which appears on the left wing of the airplane velocity vector symbol. The upper left FMA window repeats the MSP speed window provided the airplane speed at the time time the speed HOLD button was pushed is above the minimum allowable airplane speed, which is a function of configuration, and below the

flap placard speed. If the airplane calibrated airspeed is below the minimum allowable airspeed when SPD HOLD was pushed, the FMA speed reference value will slew to the minimum allowable airspeed for the flap setting. Unless flaps are completely deployed, the pilot will see a FMA lower flap message. Similarly, if the calibrated airspeed is above the flap placard speed when the speed HOLD button was pushed, the FMA reference speed will slew to the flap placard speed. Raise flap messages will appear on the FMA message panel until the pilot raises the flaps to clear the message. When the speed HOLD button is pushed, the FMA shows $\boxed{\begin{array}{l}\text{121}\\ \text{SPD}\end{array}}$ for an example speed reference of 121 knots which is above the minimum allowable powered lift speed and below the flap placard speed. The speed reference is an input to the SCAS system for modes F, C or B and an input through the blending coefficients to the pitch and power-lever directors for modes O, M or B.

Push SPD HOLD from ON to OFF	The MSP speed window does not change. The speed reference input to the EADI/HUD speed director symbology is removed but the pitch and power-lever directors will not disappear for modes O, M or B if path information is available to drive those directors. The speed reference for SCAS modes F and C is removed. Both FMA speed windows are blank.

Set the speed window and push SPD SEL (SPD HOLD is off)

The MSP speed window is solid and shows the value set by the pilot using the slew knob. Upon pushing SPD SEL, the FMA speed arm window (the upper left window) alternates between speed displayed in knots and SPD. The number in the upper left FMA window, which is the reference for the speed flight director symbology, smoothly progresses toward the MSP speed window at a rate of 1 kt/sec if the calibrated airspeed is below the flap placard speed or above the powered-lift minimum speed. If the airspeed is outside of the acceptable speed range, the FMA window value slews to the allowable reference speed. When the airplane speed is the same as the MSP window speed, the FMA shows $\boxed{\begin{array}{l}121\\ \text{SPD}\end{array}}$ for an example speed of 121 knots. HOLD will only be achieved if the selected speed is within the acceptable speed range. While in SPD SEL, the pilot may change the MSP speed window value using the speed knob. However, the speed director symbology remains referenced to the allowable airspeed shown in the FMA speed arm window.

With SPD HOLD ON or FR HOLD ON, set the MSP speed window and push SPD SEL

The MSP window shows the speed selector knob setting. If the setting is different than either the airplane calibrated airspeed in knots or flight reference in percent, the MSP window blinks until SPD HOLD or FR HOLD is achieved. The upper left window of the FMA, the speed select window, shows either a solid speed reference number or else alternates between the speed reference number and the symbol SPD to show the arm state. Upon pushing SPD SEL, the operation is the same as described for "Set the speed window and push SPD SEL (SPD hold is off)."

With SPD HOLD ON, set the speed window

The FMA continues to show | 121 SPD | for an example instantaneous reference speed of 121 knots. If the MSP speed window is different than the existing reference value, the MSP speed window blinks ON and OFF. If the pilot pushes SPD HOLD OFF and ON, the MSP speed window will be reset to the existing airplane airspeed and the window will be solid. If the airplane airspeed is within acceptable maximum or minimum limits, the FMA speed select window (the upper left window) will progress at a constant rate towards the MSP window. Otherwise, the FMA window will go to the acceptable speed boundary.

With SPD SEL active, push HOLD

The FMA progresses from | |, where the upper left window shows SPD 121-SPD-121..., to | 130 SPD | at 1 kt/sec for an example where the MSP window was set to 121 knots and the existing airplane was 130 knots when the SPD HOLD was pushed. In this example, the airspeed is assumed to be within the range of acceptable speeds. Otherwise, the FMA would go to the allowable maximum or minimum speed. The MSP speed window stops blinking and shows the speed of the airplane when the HOLD button was pushed. The director symbology is referenced to the FMA speed arm window value.

Push SPD SEL from On to OFF

The MSP speed window becomes solid at the airspeed of the airplane when the SPD SEL button was pushed. The upper left window of the FMA progresses towards the reference speed which either replicates the MSP speed window or is an acceptable minimum or maximum speed for the configuration. SPD SEL is replaced by SPD HOLD and the speed error symbology is referenced to the FMA upper left window. The FMA goes to $\boxed{\begin{array}{l}121\\ SPD\end{array}}$ for an example MSP airspeed of 121 knots.

Push FR HOLD from OFF to ON	The MSP speed window shows the safety margin percentage at the time the FR HOLD button was pushed. Both the upper left window of the FMA and the safety margin target symbol (>) show the reference safety margin for the speed flight director symbology. The upper left FMA window and the safety margin target value (>) repeat the MSP speed window provided the safety margin is equal to or greater than 100% when the FR HOLD button was pushed. If the safety margin symbol (◇) is below 100% when FR HOLD is pushed, the FMA and repeating (>) symbol slew up to 100%. For an example safety margin target value of 115%, the FMA shows $\boxed{\begin{array}{l}115\\ FR\end{array}}$. The flight reference is an input to the SCAS system for modes F, C or B and an input to the speed symbology through blending coefficients for the pitch and power lever directors for modes O, M or B.
Push FR HOLD from ON to OFF	The MSP speed window does not change. The flight reference input to the EADI/HUD speed director is removed for modes O, M and B but the pitch and power-lever directors will not disappear if pitch information is available to drive those directors. The speed

reference is removed as an input to SCAS modes C, F or B. The safety margin target symbol (>) is removed from the EADI/HUD and both FMA speed windows are blank.

Set the Speed Window and push FR SEL (FR HOLD is OFF and SPD HOLD is OFF)

The MSP window is solid and shows the target percentage of safety margin set by the pilot using the speed knob. Upon pushing FR SEL, the FMA speed arm window (the upper left window), which is the reference for the speed flight director symbology for modes O, M or B or the reference for SCAS modes F, C or B, alternates between the reference safety margin percentage and FR. The number in the upper left FMA window smoothly progresses toward the MSP speed window setting at a rate of 2%/second if the number in the MSP window exceeds 100%. Otherwise, the FMA window will slew to a minimum limiting value of 100%. The speed safety margin target symbol (>) repeats the MSP speed window setting. When the safety margin is within 2% of the MSP speed window setting, the FMA shows 110 FR for an example MSP speed window setting of 110%. FR HOLD can only be achieved if the selected flight reference is greater than or equal to 100%. While in FR SEL, the pilot may change the MSP speed window setting using the speed knob. However, the speed director symbology or SCAS speed inputs remain referenced to the percentage shown in the FMA speed arm window.

With either SPD HOLD or FR HOLD ON, set the MSP speed window and and push FR SEL

The MSP window shows the slew knob setting. If the number in the window is different than either the calibrated airspeed in knots or safety margin in percent, the MSP speed window blinks on and off until FR HOLD is achieved. The FMA speed window (the upper left window) shows a solid safety margin reference number until FR SEL is pushed and then alternates between the safety margin number and the symbol FR to show the arm state. After FR SEL is pushed, the operation is the same as described for "Set the speed window and push FR SEL (FR HOLD is OFF and SPD HOLD is OFF)."

With FR HOLD ON, set the speed window

The FMA continues to show 110 FR for an example MSP safety margin of 110%. If the MSP speed window is different than the existing safety margin reference value, the MSP window blinks OFF and ON. If the pilot pushes the FR HOLD off and on, the MSP speed window will reset to the existing safety margin percentage if the safety margin is greater than 100% or to 100% if the safety margin is less than 100% and the window will become solid. If the airplane safety margin exceeds 100%, the FMA speed arm window (the upper left window) will progress at 2%/second towards the MSP window. If the safety margin is less than 100%, the FMA window slews to 100%.

With FR SEL active, push FR HOLD

The FMA jumps from , where the upper left window shows 100-FR-100..., to 115 FR for an example where the MSP window was set at 100% and the existing safety margin was 115% when the FR HOLD button was pushed. In this example, the safety margin was greater than 100%. If the safety margin was less than 100%, the FMA would slew to a minimum value of 100%. The MSP speed window stops blinking and shows the safety margin of the airplane when the FR HOLD button was pushed. The flight director speed symbology or SCAS speed inputs are referenced to the FMA speed arm window value.

Push FR SEL from ON to OFF	The MSP speed window becomes solid at the safety margin percentage which existed when the FR SEL button was pushed except that if the safety margin value was less than 100%, the window would jump to 100%. The upper left window of the FMA slews towards the MSP speed window value. FR SEL is replaced by FR HOLD and the flight director speed symbology or SCAS speed input is referenced to the FMA upper left window. The FMA goes to $\boxed{\begin{matrix}105\\ \text{FR}\end{matrix}}$ for an example MSP speed margin of 105%.

The speed configuration (SPD CONF) button is used in conjunction with flight director modes O and M to reduce pilot work load by relieving the pilot of the task of setting reference speed after each flap selection. This is accomplished by making the speed reference a function of the outboard and USB flap setting. This feature will most likely be used in conjunction with the reference flight paths to be discussed later. The relationship of SPD CONF to the reference flight paths is the reason the SPD CONF button is grouped with the guidance modes as shown in the MSP layout, Figure 8. However, the SPD CONF button can be used with any lateral and vertical mode at the pilot's discretion. The button pushing response is described below.

Action	System Response
Push SPD CONF from OFF to ON (LIFT/DRAG is OFF)	Turning SPD CONF ON causes the MSP speed window to be set to the final approach airspeed and links the FMA speed reference to the outboard and USB flap settings. The FMA speed arm window (upper left window) shows the reference speed for the EADI/HUD flight director speed symbology. This reference speed varies with the outboard and USB flap setting and progresses down as first the outboard and then the USB flaps are extended. The FMA shows [121 CONF] for an example speed of 121 knots. Any other SPD or FR HOLD or SEL button, which may be on, will be turned off when SPD CONF is selected. The SPD CONF button will also supersede the SPD PROF button which is associated with AREA NAV to be discussed later.
Push SPD CONF from OFF to ON (LIFT/DRAG is ON)	The SPD CONF mode will not engage when the power-lever servo is engaged since SPD CONF is used with the flight director modes only. An attempt to push SPD CONF will result in the caution message "LIFT/DRAG IS ON."
Push SPD CONF from ON to OFF	The FMA speed windows are blank until the pilot makes another speed selection. In the absence of another selection, the airspeed reference input to the pitch director and power-lever director is removed. If a vertical mode is not also selected, the power-lever director will disappear and the pitch director will either disappear, if there is no lateral guidance, or will appear yellow to denote that only lateral guidance remains active.

Guidance Modes

Three levels of guidance modes are available for the QSRA. The first level is the standard TACAN or VOR which provides azimuth and DME information for guidance along tracks that pass directly over the navigation stations. The second level consists of ILS and MLS approach aids. ILS provides localizer and glideslope guidance to a line in space. MLS provides wide angle azimuth and elevation coverage as well as DME. Azimuth, elevation and DME information is processed in a computer to provide precision guidance for a wide range of approach azimuth and glideslope angles. Only the azimuth angle associated with the runway centerline is of interest for the QSRA. When used in conjunction with a radio altimeter, both the ILS and MLS systems permit Category II and Category III landing guidance. The third level of guidance uses an onboard digital computer to provide both three dimensional (3D) and four dimensional (4D) curved, descending and decelerating approaches. The QSRA research program will emphasize 3D area navigation operation along prestored and computer generated flight paths with speed control provided primarily for fuel minimization rather than for the precise time sequencing associated with 4D.

The TACAN, VOR, ILS, MLS and AREA NAV guidance modes available on the QSRA are mutually exclusive. That is, only one of these modes can be active. However, more than one mode can be armed. Since TACAN, VOR and AREA NAV can be multiply armed, there is a question about which of these modes has priority over the other for coupling. If the TACAN, VOR, and AREA NAV guidance sources are all armed simultaneously, the first of these sources that satisfies a capture criterion will provide the guidance reference until replaced by an approach guidance source or until the pilot makes another selection by turning off the active source. Automatic transitions can take place from the enroute guidance sources, TACAN, VOR or AREA NAV, to MLS approach guidance and from TACAN or AREA NAV to ILS. Automatic transitions from VOR to ILS are precluded because only a single VHF navigation receiver is available for the QSRA digital flight control system. TACAN, VOR or AREA NAV may be armed or coupled at the same time that MLS is armed. TACAN or AREA NAV may be armed or coupled simultaneously with ILS arm. Transition from the enroute guidance sources, TACAN or VOR, to MLS will take place automatically when the airplane enters the MLS centerline capture region provided the azimuth and DME signals are valid. Glideslope transition depends on a valid elevation signal. Transition from TACAN to ILS will take place automatically provided the ILS localizer is valid and the pilot has designated the proper ILS mnemonic at the keyboard. AREA NAV will automatically transition to ILS or MLS at the reference flight path waypoint designated as the final waypoint provided the approach aid is valid and provided that when the airplane passes the final waypoint, the airplane is within the approach aid capture region. The guidance buttons on the MSP provide the means to select TACAN, VOR, ILS, MLS or AREA NAV guidance sources.

The Kalman filter navigation system described earlier uses all valid enroute and approach navigation sources that are enabled to determine the aircraft position. Since the navigation enable buttons and the guidance buttons on the MSP are separate, the Kalman filter provides a means to navigate on a TACAN or VOR radial without the TACAN or VOR providing a valid navigation signal into the Kalman filter. The TACAN or VOR guidance buttons and the course window provide the reference radial which, when differenced with the Kalman filter position estimate, provides the lateral guidance error signal. It is therefore possible to fly a TACAN or VOR radial using a dead reckoning estimate based only on INS velocity integration.

As noted earlier in the discussion on navigation, the pilot is responsible for correctly entering the TACAN, VOR or ILS navaid station mnemonic and for tuning the corresponding receiver frequency or channel. Radials can be flown from only the TACAN or VOR station current in memory. In general, the corresponding TACAN or VOR navigation receiver should be valid to insure navigation accuracy but because of the Kalman filter dead reckoning capability using INS, guidance for TACAN or VOR radials does not depend on navigation valids. The system does provide the pilot with alert messages so he will be aware that navigation may not be accurate. When dead reckoning begins, the FMA message panel displays "DEAD RECKONING." If the pilot selects TACAN or VOR for guidance and the corresponding navaid is not valid, the FMA message is "CHECK NAVAID." The pilot may use the navigation status information on the MFD to assess the validity of the navigation system. In the discussion which follows, the navigation system is assumed to be functional.

TACAN and VOR

The Tacan and VOR flight director modes function in precisely the same way. The description which follows is stated in terms of TACAN operations. The VOR functions in exactly the same way and VOR operations will not be separately described.

Action	System Response
Select a CRS and push TAC ON	The MSP CRS window and the HSI course select pointer shown in Figure 8 indicate the course reference setting. If the airplane is outside the capture region, the pilot must establish the intercept heading to fly the airplane into the capture region. When the TAC guidance button is pushed on, the LAT NAV button is automatically pushed to establish lateral guidance, the FMA shows $\boxed{\quad\quad\text{TAC}}$ and the HSI CDI becomes active. If the capture criterion is satisfied but the track criterion is not, the FMA shows $\boxed{\quad\quad\text{TAC}}$ and the EADI/HUD lateral flight director () provides capture guidance to the MSP course window reference setting. As noted earlier, if a vertical mode is also active, the EADI flight director symbology is pink. If only the lateral director is active, the EADI flight director is yellow. If the track criterion is also satisfied,

the lateral mode flight director is referenced to the MSP CRS window setting and the FMA continues to show $\boxed{\text{TAC}}$. If the airplane is overstation, the system automatically goes to HDG HOLD referenced to aircraft heading at the beginning of the overstation passage, the HSI TO-FROM flag changes state, the FMA shows $\boxed{\begin{array}{r}\text{TAC}\\ \text{HDG}\end{array}}$ and the EADI/HUD lateral flight director symbology is referenced to the MSP HDG window value. Once past the station, the EADI/HUD flight director symbology reverts to TACAN radial track referenced to the MSP CRS window setting and the FMA shows $\boxed{\text{TAC}}$.

A new radial can be selected at any time using the CRS slew knob as follows. The system will automatically go to HDG HOLD when the CRS knob is moved more than five degrees and system operation is a function of the following possible existing conditions: a) Inbound and outbound courses: If the radial change is less than five degrees, the system will automatically go out of the HDG HOLD mode when the CRS knob is moved and flight director guidance will be provided to capture and track the new radial. If the radial change is greater than five degrees, the system will remain in HDG HOLD after the new radial is selected. The pilot may use HDG SEL to establish flight director guidance to the new radial or manually fly the airplane to capture the new radial. b) Course selection when overstation: If a new outbound radial is selected when the system is in HDG

HOLD overstation, the system will continue in HDG HOLD until overstation passage is complete. Flight director guidance will be provided to capture and track the selected outbound radial.

ILS and MLS

Two approach receivers, ILS and MLS, will be available in the QSRA for flying precision approaches. Primary emphasis will be placed on MLS but the possibility still exists of operating with ILS. Several ways of entering into ILS or MLS coverage are available. The pilot can manually fly the airplane into the coverage, engage the flight director to activate the FPA HOLD and HDG HOLD modes and then transition immediately to ILS or MLS. He can use the pilot assist features, HDG HOLD or SEL and FPA or ALT HOLD and SEL, prior to entering the ILS or MLS coverage. He can use TACAN or VOR-DME radials to intercept the ILS localizer or MLS centerline. Finally, he can use the area navigation feature to establish a curved descending entry to the ILS or MLS final approach. The manual entry to ILS localizer and glideslope intercepts will be described for the ILS. The other possible entries will be outlined for the MLS.

From an operational point of view, the ILS can be regarded as a subset of the MLS in the sense that an ILS provides only a centerline reference and a single glideslope angle reference whereas the MLS provides a wide range of possible azimuth angles and glideslope angles. Typically, MLS azimuth is restricted to the runway centerline but the glideslope angle can vary from 3 degrees for conventional airplanes to greater than 7 degrees for powered-lift STOL airplanes. THe QSRA is capable of flying both the 3 degree ILS glideslope as a conventional jet transport and the 6 degree MLS glideslope as a STOL airplane. The QSRA can be flown on the ILS using flight director modes O and M with outboard flaps extended and the USB flaps set near 30 degrees so the airplane has frontside characteristics. The ILS can also be flown using the frontside SCAS system, mode F, which provides automated speed control and causes the airplane to behave in pitch like a conventional jet transport. In the description which follows, the pilot is assumed to be using flight director modes 0 or M and to make use of the SPD PROF mode to establish the approach speed director reference. Prior to pushing the ILS guidance button on the MSP, the pilot must tune the VHF ILS frequency and establish that the frequency is appropriate to the intended airport of landing. If the pilot has selected VOR on the HSI VOR/MLS selector (Figure 7) the CDI will show displacement from the localizer and the VDI will show glideslope deviation provided the respective localizer and glideslope signals are valid. The HSI is not under control of the MSP ILS guidance button so HSI ILS indications will not be described subsequently. Since the Kalman filter is used to smooth the ILS localizer and glideslope signals, the pilot must be sure that the station identifier mnemonic is selected at the keyboard so navigation is consistent with the selected airport of intended landing and that both localizer and azimuth are enabled as inputs to the Kalman filter. If the pilot attempts to select the ILS guidance button before selecting ILS navigation, the ILS navigation button is selected automatically. If localizer and glideslope are not enabled at the keyboard, the FMA message panel displays "ENABLE ILS." When the pilot selects the ILS station identifier mnemonic, the approach course and the glideslope angle for the specific ILS approach aid are stored in the computer and will be displayed in the MSP course and glideslope windows when ILS is armed.

<u>Action</u>	<u>System Response</u>
Fly the airplane into ILS localizer coverage, push FD1 ON, push ILS ON and push SPD CONF.	Pushing FD1 on activates the FPA HOLD and HDG HOLD modes so the FMA shows $\boxed{\text{FPA HDG}}$. Pushing the ILS guidance button on causes the course and glideslope windows to be set to values appropriate to the ILS navaid identifier stored in computer memory, causes the path deviation to appear on the EADI/HUD showing the airplane deviation from the localizer and glideslope and automatically activates the LAT NAV button so the FMA shows

FPA ILS since, in this example, the airplane is assumed to already be in localizer coverage.

The mode O or M lateral flight director ( ) provides steering commands to track the localizer while the vertical flight director ( ) commands the flight path angle which existed when FDI was pushed on. The pilot must subsequently push VERT NAV to arm the glideslope for capture and when he does, the reference glideslope line and the downward flight path angle capability line segments (‾_‾ ‾_‾ ‾_‾ ‾_‾) snap into view on the EADI/HUD. Since the airplane is assumed to be within localizer coverage, the FMA shows ILS FPA ILS prior to glideslope capture. If a DME signal is available, a perspective runway can also be presented on the EADI/HUD. Note that the system does not permit capture of the glideslope until the airplane is within the localizer capture region. Once the lateral and vertical references are established, the pilot may choose to add a speed reference. In this example, the pilot is assumed to have chosen SPD CONF so the speed reference will automatically be set as the flaps are extended. To establish a speed reference, the pilot pushes SPD CONF so the FMA speed reference becomes a function of outboard and USB flap settings. The FMA shows 121 ILS CONF FPA ILS for an example reference airspeed of 121 knots. Then the airplane enters the glideslope capture region, the go-around guidance mode is armed, the flight director symbology provides both lateral and vertical guidance and the FMA shows

☐	G/A	G/A
CONF	ILS	ILS

where the upper left window displays 121-G/A-121.... The airplane proceeds from glideslope capture to glideslope track without a change of mode annunication on the FMA. If the ILS localizer and glideslope signals become invalid during the approach, the flight director reverts to FPA and HDG HOLD and the message "ILS INVALID" is presented to the pilot on the FMA message panel. The FMA also indicates that although ILS has reverted from couple to arm, the go-around mode is still armed. Assuming the localizer and glideslope signals remain valid, ILS tracking continues to decision height. The decision height is entered by the pilot in computer memory using the keyboard mnemonic DHT. Below the decision height, the path deviation box continues to show the error from the localizer and glideslope until the airplane reaches a radio altimeter height of 13.7 m (45 ft). Below 13.7 m (45 ft), the path deviation is referenced to a nominal altitude - altitude rate flare path that terminates in the runway touchdown zone. The FMA shows

☐	G/A	G/A
LAND	LAND	ILS

where the upper left window alternates between a landing airspeed reference and go-around, the flight director symbology is driven by an altitude-altitude rate flare law that provides guidance to a soft touchdown within the runway touchdown zone and by a speed reference which drops from the landing reference airspeed to 10 knots below that speed at a rate of

2 kt/sec. The pilot is not expected to complete the landing using the flight director, however, all command information presented to the pilot is consistent with a reasonable landing. Lateral guidance based on the localizer signal continues throughout the rollout. The go-around mode is cancelled when the airspeed drops below 30 knots.
At any time during the approach and landing after go-around is armed and prior to airspeed dropping below 30 knots, the pilot can initiate go-around guidance by pushing the go-around switch located on the #1 power-lever. When go-around is activated, the FMA shows

72		
G/A	G/A	G/A

, where 72 knots is an example of safe airspeed, the EADI/HUD path deviation box disappears, the EADI/HUD reference glideslope and downward flight path angle capability symbols (-_- -_- -_- -_-) are removed, localizer tracking continues, glideslope tracking is discontinued and replaced by flight director guidance to establish a + 1 degree flight path angle climb and a safe climb airspeed. After attaining a safe climb airspeed, the system provides guidance to a maximum rate of climb. Localizer tracking continues until the localizer signal is lost. Then SPD HOLD provides guidance at the safe climb airspeed, FPA HOLD replaces the go-around maximum rate of climb and HDG HOLD replaces the go-around localizer track. The FMA then shows

SPD	FPA	HDG

until the pilot selects replacement modes or turns the flight director off.

Push ILS from ON to OFF	The ILS guidance is turned off, go-around arm is cancelled and the FPA HOLD and HDG HOLD modes are activated so the FMA shows $\boxed{\text{FPA HDG}}$. The perspective runway, approach glideslope reference symbol and maximum downward flight path angle reference lines are removed from the EADI/HUD. The flight director symbology is referenced to the flight path angle and heading which existed when the ILS button was turned off.

Prior to beginning an MLS approach, the pilot must select a glideslope angle, choose one of the flight director or SCAS modes to be used and decide upon an intercept procedure. In the event that MLS has not previously been selected as a navigation input to the Kalman filter, pressing the MLS guidance button will automatically select the MLS navigation button. If the pilot has not enabled all three components of MLS at the keyboard, the MLS guidance button cannot be turned on and the FMA message panel displays "ENABLE MLS." Because only a single experimental MLS transmitter is available to the QSRA, the pilot is relieved of the requirement to tune the MLS receiver and enter a location mnemonic in the computer. MLS can be armed for capture even though the airplane is outside the segment of airspace where both the azimuth and DME signals are valid. If the pilot has selected MLS on the HSI VOR/MLS selector (Figure 7) the CDI will show displacement from the course selcted on the MSP, the VDI will show displacement from the glideslope selected on the MSP and the left DME window will show range to the MLS DME transmitter provided the airplane is in coverage of the MLS azimuth, elevation and DME and the signals are valid. The HSI is not under control of the MSP MLS guidance button so HSI MLS indications will not be discussed subsequently. As noted earlier in connection with the ILS description, MLS tracking can be initiated in four ways: using the MLS button after the flight director is first turned on, using FPA or ALT and HDG pilot assist modes to fly into MLS coverage, entering MLS coverage from a TACAN or VOR radial or by transitioning to MLS from AREA NAV. The last three options will be described here. In the first case to be described below, the flight director mode, either 0 or M, is selected, altitude hold is selected and MLS is armed while the airplane is still outside of MLS azimuth coverage. To provide an example of a speed reference different than was discussed in connection with ILS, the pilot is assumed to be looking after the speed using the MSP SPD SEL and SPD HOLD buttons. The mode annunciation is indicated for each phase of the approach in Figure 20.

Action	System Response
Push FD1 ON, push ALT HOLD ON, push SPD HOLD ON and push MLS ON	When FD1 is pushed on, the flight director symbol ( ) appears on the EADI/HUD, colored pink on the EADI, and both vertical and lateral guidance is provided to hold the engage values of flight path angle and altitude. THE FMA registers FPA HDG. The pilot then selects the ALT HOLD mode to maintain altitude and SPD HOLD to maintain speed and the FMA registers 130 SPD ALT HDG where 130 knots is the aircraft speed when SPD HOLD was pushed. Next the pilot pushes MLS on. The course and glideslope windows are set to values for the MLS identifier mnemonic stored in computer memory. The glideslope will nominally be 6 degrees but the pilot may select his choice of the glideslope reference angle with the G/S knob and this reference will remain in memory until the pilot makes a new selection. Pushing MLS automatically activates the LAT NAV button and the FMA shows 130 MLS SPD ALT HDG. The pilot must subsequently push VERT NAV to arm the glideslope for capture and when he does, the FMA shows 130 MLS MLS SPD ALT HDG. When both MLS lateral and vertical modes are armed, the EADI/HUD path deviation box shown in Figure 5 comes into view located at full scale de-

flection until the airplane is within the proportional signal region and then shows deviations from the MLS centerline and glideslope. The pilot assist modes guide the airplane into a region where the MLS lateral capture criterion is satisfied. In the example shown in Figure 20, the airplane is initially established on a heading different than that needed for MLS centerline intercept. The pilot uses the HDG SEL feature to establish a MLS centerline intercept heading. The pilot enters his planned landing USB flap setting into the keyboard using the mnemonic, LFP. The computer uses the landing USB flap setting and the aircraft weight to calculate the landing approach airspeed in knots and this number is the minimum value to which the MSP speed window can be set using the speed knob. The pilot slews the MSP speed window to its minimum value to set the final approach airspeed reference. The FMA speed window value will slew to the MSP speed window value at 1 kt/sec until a minimum speed for the flap setting is encountered and will hold that speed reference until the flaps are extended further. When the flaps are extended to the planned setting, the FMA speed window will progress to the MSP speed window value at 1 kt/sec until the two windows coincide. The pilot may choose another setting for the final approach speed provided the new setting is greater than the computer generated landing approach airspeed. When the airplane flies into the MLS lateral capture region, the EADI/HUD lateral flight director symbology ( ) provides command guidance to capture the MLS centerline and the FMA shows | MLS / ALT MLS | where the speed window alternates between the current speed reference value and SPD. The perspective runway on the EADI/HUD "swims" into view as the airplane rolls onto the MLS centerline. When the airplane crosses into a region where the MLS elevation signal is valid, the FMA shows | MLS MLS | where the speed window still alternates between the current speed reference value and SPD. The pilot may inhibit the MLS glideslope capture and tracking guidance by pressing VERT NAV off or by selecting an altitude or flight path mode on the MSP. In the discussion to follow, the MLS VERT NAV is assumed to be on. When MLS is armed the glideslope reference and the downward capability line segments (‾_‾ ‾_‾ ‾_‾ ‾_‾) snap into view on the EADI/HUD. Note that the system does not permit capture of the glideslope until the airplane is within the centerline capture region. When the airplane enters the glideslope capture region, the go-around guidance mode is armed, the flight director symbology provides guidance to both the centerline and the glideslope and the FMA shows | G/A G/A / SPD MLS MLS | where the speed window alternates between the reference speed, SPD and G/A. The airplane proceeds from glideslope capture to glideslope track without a change of mode annunication on the FMA. Once stablized on the MSP set approach speed, SPD HOLD is achieved and the FMA speed window alternates between the reference speed and G/A. MLS tracking continues to decision height, which is entered in computer memory through the keyboard using the mnemonic, DHT. Below the decision height, the path deviation box continues to show the error from the centerline and glideslope until the airplane reaches a radio altimeter height of 13.7 m (45 ft). Below 13.7 m (45 ft), the path deviation box is referenced to a nominal altitude-altitude rate flare path that terminates in the STOLport touchdown zone. The FMA shows $\boxed{\begin{array}{ccc} \square & \text{G/A} & \text{G/A} \\ \text{LAND} & \text{LAND} & \text{MLS} \end{array}}$ where the speed window alternates between G/A and the reference speed which bleeds off from the landing approach airspeed to 10 knots below that speed at a rate of 2 kt/sec and the flight director symbology is driven by an altitude-altitude rate flare law that provides guidance to a soft touchdown within the STOLport touchdown zone. The pilot is not expected to complete the landing using the flight director, however, all command information presented to the pilot is consistent with a reasonable landing. Lateral guidance based on centerline azimuth error continues throughout rollout. The go-around mode is canceled when the airplane airspeed drops below 30 knots. At anytime during the approach and landing after go-around is armed and prior to airspeed dropping below 30 knots, the pilot can inititate go-around guidance by pushing the go-around switch located on the #1 power-lever. When go-around is activated, the FMA shows $\boxed{\begin{array}{ccc} 90 & & \\ \text{G/A} & \text{G/A} & \text{G/A} \end{array}}$ where 90 is the safe climb airspeed, the EADI/HUD path deviation box disappears, the EADI/HUD reference glideslope and downward flight path angle capability symbols (-_- -_- -_- -_-)

are removed, centerline tracking continues, glideslope tracking is discontinued and replaced by flight director guidance to establish a + 1 degree flight path angle climb. After attaining a safe climb speed, the system provides guidance to a maximum rate of climb. Centerline tracking continues until the MLS azimuth signal becomes invalid. Then SPD HOLD replaces the go-around reference speed, FPA HOLD replaces the go-around centerline track. The FMA shows [90 / SPD FPA HDG] until the pilot selects replacement modes or turns the flight director off. In the event of loss of the glideslope signal, the flight director reverts to FPA HOLD referenced to the MSP glideslope angle window, the FMA shows [☐ G/A G/A / SPD FPA MLS] where the speed window alternates between 68 knots, the landing approach airspeed, and G/A and the message "G/S INVALID" appears on the FMA message panel. If the pilot presses the go-around button, the FMA shows [90 / G/A G/A G/A] and the transition to a + 1 degree flight path angle begins. If the MLS azimuth signal is lost, the flight director reverts to FPA HOLD and HDG HOLD, the FMA shows [90 / SPD FPA HDG] and the message "MLS INVALID" appears on the FMA message panel.

Push MLS from ON to OFF

The MLS guidance mode is turned off, go-around arm is cancelled and the FPA HOLD and HDG HOLD modes are activated so the FMA shows [FPA HDG]. The perspective runway, approach glideslope reference symbol and downward flight path angle reference lines are removed from the EADI/HUD. The flight director symbology is referenced to the flight path angle and heading which existed when the MLS button was turned off.

Push MLS ON while in TACAN track and ALT HOLD

The MLS capture from TACAN sequence, shown in Figure 21, begins, as do all flight director modes, by pushing the flight director button, FD1. The FMA registers $\boxed{\text{FPA HDG}}$. In this case, the pilot is assumed to be looking after speed without using any MSP selected speed reference. The pilot selects an altitude with the altitude knob, pushes ALT SEL and soon achieves the ALT HOLD mode shown in Figure 21 at which point the FMA indicates $\boxed{\text{ALT HDG}}$. To establish the track leading to the MLS centerline, the pilot selects a course to the TACAN navaid, pushes the TAC guidance button and then arms MLS by pushing the MLS guidance button. Figure 21 shows a situation where the airplane is maintaining altitude and heading and is armed to capture the TACAN radial leading to the MLS centerline. At this point, the FMA shows $\boxed{\text{ALT HDG}}$ with the lateral arm window alternating between TAC and MLS to show both are armed for capture. Figure 21 shows that to start the turn into the TACAN course, the pilot has used the heading select feature so the FMA indicates $\boxed{\text{ALT}}$ with the lateral arm window sequencing through TAC-MLS-HDG-TAC.... When the airplane has captured and then is tracking the TACAN course, the FMA indicates $\boxed{\begin{array}{r}\text{MLS}\\ \text{ALT TAC}\end{array}}$. When the pilot is ready to arm the MLS glideslope, he pushes VERT NAV and the FMA shows $\boxed{\begin{array}{r}\text{MLS MLS}\\ \text{ALT TAC}\end{array}}$. Upon entering the MLS capture region, the FMA shows

	MLS	
	ALT	MLS

and thereafter the vertical and lateral mode operation is the same as described for "Push FD1 ON, push ALT HOLD ON, push SPD HOLD ON and push MLS ON."

Push MLS ON while in VOR/DME track and ALT HOLD

The operation is the same as for entering MLS from TACAN.

Push MLS ON while in AREA NAV

The next discussion assumes that the lateral, vertical and speed AREA NAV references, to be described later, are active. The MLS lateral and vertical modes can be armed for capture by pushing MLS even though the airplane is outside of the region where MLS azimuth and DME are valid. When the MLS lateral mode is armed, the MSP course window is set to the centerline reference value. The FMA shows

130		MLS
ANAV	ANAV	ANAV

where 130 knots is the current reference speed. The MLS vertical mode is armed for capture by pushing VERT NAV subsequent to the MLS button. Then the FMA shows

130	MLS	MLS
ANAV	ANAV	ANAV

and the MSP glideslope window is set to the MLS glideslope value which is nominally 6 degrees. When the airplane passes the final waypoint, as designated through a keyboard entry, the MLS centerline and glideslope track references are used for the flight director symbology and the FMA shows

	G/A	G/A
SPD	MLS	MLS

where the speed window alternates between the MSP speed reference and G/A. Thereafter, the system responds as described for "Push FD1 ON, push ALT HOLD ON, push SPD HOLD ON and push MLS ON."

Multiple Mode Arming

Situations can occur where the pilot has armed more than one vertical mode. In the most extreme situation, there is a short period of time in which up to three vertical modes can be armed simultaneously. Annunciation in the FMA vertical mode arm window consists of repeating the mnemonics for the modes armed, for example, in the sequence MLS-ALT-FPA-MLS.... MLS has the highest priority followed by ALT in turn followed by FPA. If the pilot does not wish the above sequence of modes to be followed, he must assume responsibility for cancelling any mode that he decides not to use.

Multiple arm situations can also occur for the lateral modes. Figure 21 shows an example of multiple lateral modes that are armed. The arm messages appear in the FMA lateral arm window as MLS-TAC-HDG-MLS.... MLS capture will have higher priority than TACAN capture. TACAN capture will in turn have higher priority than heading capture. This sequence is determined by the precision of the guidance source. If MLS is armed and the pilot wishes to supercede the MLS centerline track with a TACAN radial track, he must cancel MLS arm by pushing MLS off.

Area Navigation

The QSRA digital flight control system incorporates an area navigation guidance system activated by the AREA NAV button. The area navigation system provides lateral, vertical and speed guidance references for flight director modes O and M or SCAS modes C and F. The approach path may be one of the four prestored reference flight paths selected at the multifunction display control panel (MFDCP) or a minimum fuel path synthesized in the onboard computer when the trajectory generation (TRAJ GEN) is pushed or a composite path made up of an initial synthesized path segment combined with a final prestored path segment.

Pushing the AREA NAV button automatically activates the LAT NAV button which in turn arms lateral guidance. The pilot pushes VERT NAV to arm vertical guidance. Various speed references can be added: basic pilot assist speed modes (SPD or FR HOLD or SEL), speed as a function of the outboard and USB flap settings (SPD CONF) or a speed reference which is associated with the prestored reference flight path which may be combined with the trajectory generation path (SPD PROF).

Once a reference flight path and an initial waypoint have been selected, capture of an area navigation path can be accomplished in the same way as capture of a TACAN or VOR radial or an ILS localizer or an MLS centerline. The pilot can fly the airplane into the path capture region, activate the flight director and then push the AREA NAV button or he can use the FPA or ALT and HDG pilot assist modes to guide the airplane into the reference path capture region or he can use TACAN or VOR radials to enter the reference path capture region or finally, he can use the TRAJ GEN button to set up the path capture. The procedure using pilot assist modes for path capture will be covered in detail first and then the other procedures will be outlined.

Area Navigation Using Pilot Assist Modes

Figure 22 shows the procedure and annunication associated with pilot assist modes for capturing a reference flight path which terminates in the capture region of the MLS centerline and glideslope. The procedure begins with the airplane presumed to be in flight at a cruise speed.

Action	System Response
Push FD1 ON, select FP2, dial WPT 2, select WPT 2 altitude, push ALT SEL, select the intercept HDG, push HDG SEL, push AREA NAV, push VERT NAV, push SPD PROF and push MLS	When FD1 is pushed on, the lateral flight director is referenced to the engage value of heading and the vertical flight director is referenced to the engage value of flight path angle. The FMA shows $\boxed{\text{FPA HDG}}$. At this point, the pilot is presumed to be looking after speed without using a flight director or SCAS speed reference. When the pilot selects flight path 2 (FP2) at the multifunction display control panel (MFDCP), a plan view of the prestored reference flight

path 2 appears on the MFD with the orientation, scale and aircraft location that exists in computer memory. The waypoint number currently in the MSP waypoint window and the altitude associated with that waypoint will appear in the lower left corner of the MFD. The location of this information is shown in Figure 6. The next pilot action is to choose a waypoint for coupling to the reference flight path by dialing the beginning waypoint number at the MSP. This waypoint number will remain unchanged until either the airplane enters the reference flight path capture region and passes the designated waypoint or until the pilot makes a new selection. Following a short delay, the duration of which is the time needed to compute and to display new information on the MFD, the capture waypoint and associated altitude appear following the MFD mnemonic, CALT. To effect the lateral capture, the pilot must establish an intercept track that carries the airplane into the capture region of a backwards extension of a straight line segment of the reference path. The capture region is defined as a function of lateral deviation and closure rate to the straight line segment preceeding the capture waypoint. To effect a lateral capture, the pilot must arm the capture by pressing AREA NAV before the airplane crosses the straight line leading to the capture waypoint. Pressing AREA NAV automatically activates the LAT NAV button. To effect a vertical capture, the pilot must fly the airplane to within ± 152 m (± 500 ft) of the capture waypoint altitude and push the VERT

NAV button before the airplane passes the waypoint. If the airplane misses the lateral capture, the pilot must select a new capture waypoint or else establish a new intercept track to cross the backwards extension line prior to reaching the capture waypoint. If the airplane misses the vertical capture, the pilot may use lateral guidance to proceed along the reference flight path and fly the airplane to an altitude which is within $\pm$ 151 m ($\pm$ 500 ft) of the next waypoint. VERT NAV remains armed until capture occurs or the pilot pushes VERT NAV off. In the example shown in Figure 22, the pilot uses the HDG SEL feature to establish an intercept track for waypoint 2 and uses ALT SEL to establish the airplane at the capture altitude. When these reference values are reached, the FMA shows

	ALT	HDG

. Then the pilot pushes AREA NAV, VERT NAV and SPD PROF to arm capture of the reference flight path to provide lateral and vertical references and to establish a speed reference based on the nominal speeds stored in computer memory for each of the waypoints. The FMA displays

▭	ANAV	ANAV
	ALT	HDG

where the upper left window alternates between the reference speed for the capture waypoint and ANAV to denote that the speed reference comes from the reference flight path speed table. When the lateral capture criterion is satisfied, the lateral flight director symbology provides guidance to fly the reference flight path track. If the vertical capture criterion is also satisfied, the flight director symbology for modes 0 and M or the combined flight director and SCAS laws for modes C and F are referenced to the path altitude table. When both lateral and vertical couple has occurred and if the SPD PROF has been armed, the reference flight path speeds will provide the reference for the power-lever symbology for modes O and M or for SCAS modes C and F. When the flight director symbology or SCAS is coupled to area navigation references, the FMA will display

120		
ANAV	ANAV	ANAV

. The speed which appears in the upper left window of the FMA is the speed for the capture waypoint until the airplane passes the capture waypoint and then will change if the reference speed for the next waypoint is different. The MFD shows the airplane position relative to the reference flight path planform, the waypoint number and altitude of the upcoming waypoint as well as the time in seconds to the next waypoint. If the WAYPT/TACAN selector on the HSI, shown in Figure 7, is set to WAYPT, the CDI shows lateral deviation and the VDI shows vertical deviation from the reference flight path, the upper right DME window shows the distance to the next waypoint and the #2 bearing pointer shows the direction to the next waypoint. As the airplane passes a waypoint, all waypoint data on the MFD and the HSI jump to the value appropriate to the next waypoint. If the SPD PROF reference speed of the waypoint just crossed is different from the reference speed for the next waypoint, the upper left FMA window displays a value which varies linearly with distance from the previous speed value to the upcoming waypoint speed value. Associated with each reference flight path is a final waypoint which is stored in computer memory. The pilot can change the final waypoint number using the keyboard mnemonic WPF. What happens at the final waypoint depends on whether or not a final approach navaid is valid and armed. The QSRA will most likely use MLS as the final approach navigation source of precision guidance. The other candidate final approach navaid is ILS.

The QSRA has an automatic navigation selection function which is activated when the keyboard mnemonic, ATN, is set to 1 and is deactivated when ATN is set to 0. If ATN is set to 1, the system will test for valid MLS azimuth and DME signals and if both signals are valid, MLS lateral guidance will be armed. When the glideslope signal becomes valid, the MLS vertical guidance will also be armed and the MSP glideslope and course windows will be set to the values stored in memory for the keyboard mnemonic for the selected MLS transmitter. The MLS glideslope is nominally set to 6 degrees unless the pilot chooses a new value and the course is set to the centerline value for the active MLS station. If MLS is not armed when the ILS localizer becomes valid, the ILS localizer and glideslope will be armed. The course and glideslope windows will be set to the values stored for the current ILS mnemonic in computer memory. If ATN is 0 and AREA NAV is engaged when MLS azimuth and DME become valid, the FMA will display "ARM MLS" unless the pilot has already armed MLS or until the message is cancelled by the pilot. Recall that pilot arming of MLS does not depend on MLS azimuth and DME being valid. The "ARM MLS" message will not be repeated unless the azimuth signal sequences through invalid and then valid, that is, unless the airplane flies out of and back into MSL azimuth coverage. If ATN is 0 and AREA NAV is engaged when the ILS localizer becomes valid, the FMA will display "ARM ILS" unless the pilot has already armed ILS or until the message is cancelled by the pilot. This message will not be repeated as long as the localizer signal remains valid. If MLS azimuth and DME become valid, testing for an ILS localizer valid will be discontinued. If the MLS azimuth and DME signals become valid after the ILS localizer is already valid, MLS arm will replace ILS arm. The logic described above will hold for the QSRA where MLS and ILS transmitters are not co-located but must be made a matter of pilot selection should MLS and ILS ever be co-located. Regardless of whether ATN is 1 or 0, if neither a complete MLS nor a complete ILS system is valid when the airplane passes the waypoint preceding the final waypoint, the pilot will get the FMA message "M/ILS-NOT VALID." If neither MLS nor ILS is armed when the airplane passes the final waypoint, the guidance reference will shift from ANAV to SPD, FPA and HDG and the message "ANAV DISCONNECT" appears on the FMA. If either MLS or ILS is armed, the FMA speed reference shifts from the reference flight path table value at the waypoint preceding the final waypoint to the value in the MSP speed window at the final waypoint. As the airplane passes the final waypoint, and provided the airplane is within the glideslope capture region for the glideslope angle shown on the MSP, the speed reference changes from ANAV to speed hold with airspeed referenced to the MSP speed window value, the go-around speed reference is armed, the lateral and vertical ANAV mode references are replaced by the MLS or ILS precision approach references and the lateral and vertical go-around modes are armed. In Figure 22, where the approach aid is MLS, the FMA goes to

▭	G/A	G/A
SPD	MLS	MLS

with the FMA speed arm window showing 68-G/A-68.... as the airplane passes the final waypoint. The reference approach airspeed is assumed to be 68 knots in the example shown in Figure 22. The guidance references and annunciation after the airplane is established on MLS glideslope are the same as described for "Push FD1 ON, push ALT HOLD ON, push SPD HOLD ON and push MLS ON."

Area Navigation using Trajectory Generate

The trajectory generate feature provides another way of coupling to one of the four prestored reference flight paths. The procedures for computing the minimum fuel path from the aircraft initial position and heading to a capture waypoint were outlined in the section on the air traffic control operating environment and will not be repeated here. There are three strategies for using the trajectory generate (TRAJ GEN) button. The first strategy is to compute a path from present position to the final waypoint. This option provides a minimum distance path to intercept the final MLS approach along with a speed-altitude descent profile. The second strategy is to synthesize a path to a capture waypoint which is a part of a prestored reference flight path. The synthesis computation will determine a minimum distance horizontal path and a speed-altitude profile to guide the airplane to a capture waypoint on one of the prestored reference flight paths. After reaching the capture waypoint, the airplane flies the prestored reference flight path track, altitude and speed to the final waypoint as was described in the previous section where pilot assist modes were used to join an AREA NAV path. If the airplane cannot fly the prestored path within bank angle, flap and power limits due to strong winds and turbulence, the airplane will deviate from the planned path and the FMA will display the message "NON FLYABLE PATH." The third strategy takes the airplane from the present position and heading to a capture waypoint on a prestored reference flight path to constrain the airplane to fly the planned track to the final waypoint but relies on the synthesis computation procedure to supply the altitude-speed profile. The third strategy is established when the number -2 appears in the reference flight path altitude or speed tables. If reasonable numbers, altitude in feet or airspeed in knots, appear in the reference flight path table, the second strategy is adopted in preference to the third strategy.

The mode engagement logic is essentially the same for all three strategies and consists of selecting one of the flight director modes O or M or SCAS modes C and F, choosing a capture waypoint and pushing the trajectory generate button. Figure 23 outlines the procedure for acquiring the MLS precision approach using the trajectory generate feature. The airplane is assumed to be in cruise flight at the beginning of the description which follows.

Action	System Response
Push FD1 ON, select a capture WPT, push TRAJ GEN ON, and push AREA NAV	When the flight director is turned on, the guidance references are flight path angle and heading. The FMA shows FPA HDG . The pilot selects one of the four reference flight paths which then appears on the MFD. The waypoint number last set on the MSP and the associated altitude also appear on the MFD. The pilot selects his choice of capture waypoint using the MSP WPT selector knob. The new capture waypoint and associ-

ated altitude appear on the MFD. The pilot begins the trajectory synthesis by pushing the TRAJ GEN button. Following a short wait while the synthesis computation is executing, a dashed line path appears on the MFD which extends from the aircraft present position and heading to a tangential intercept of the pre-stored path at the capture waypoint. As the airplane continues to fly, the dashed line capture path is continuously updated and displayed on the MFD. The FMA shows ANAV to be armed, ANAV ANAV
FPA HDG where the upper left window shows the present airspeed alternating with ANAV arm. The present airspeed is the beginning airspeed for the trajectory generation speed profile. When the pilot chooses to couple to the synthesized path, he pushes AREA ANAV which turns on LAT NAV. The pilot completes coupling to the speed-altitude profile by pushing VERT NAV and SPD PROF. When coupling to the capture path is complete, the FMA shows 152
ANAV ANAV ANAV with the upper left window showing the computer generated speed reference. The dashed capture path on the MFD is replaced by a solid path from the aircraft's present position to the capture waypoint. Computer generated lateral, vertical and speed references are used to provide flight director or SCAS guidance to first the capture waypoint and then to the final waypoint. If the first strategy is adopted, the capture and final waypoints coincide. If either the second or third strategy is adopted, the capture and final waypoints are separated. Once the airplane begins to track a capture path, that capture path becomes a backwards extension of the prestored reference flight path and the procedures and responses already described for flying a prestored flight path apply. The MFD displays all of the prestored reference flight path but only that portion of the computer generated path between the airplane's present position and the capture waypoint.

With TRAJ GEN ON but AREA NAV is OFF, PUSH TRAJ GEN OFF

Pushing TRAJ GEN off causes the dashed capture trajectory to disappear from the MFD and the ANAV speed, vertical and lateral arm indications to be removed from the FMA.

With ANAV speed, vertical and lateral coupled, push LAT NAV OFF

Vertical and speed guidance continues based on the track distances which applied when LAT NAV was on but no lateral guidance is provided to the AREA NAV path. Pushing LAT NAV off causes the lateral flight director to default to the HDG mode unless the pilot pushes HDG HOLD off to eliminate all lateral guidance. The LAT NAV off feature can be used if a poor lateral navigation signal is causing the airplane to s-turn objectionably.

APPENDIX

This appendix summarizes the abbreviations that appear on the face of the mode select panel, in the MFD or otherwise in the report text. A list of keyboard and flight mode annunciator mnemonics is provided. Finally, the flight mode annunciator messages are listed in the order of appearance in this report.

ABBREVIATIONS

ALT	Altitude
AREA NAV	Area navigation
ATC	Air traffic control
ATN	Keyboard mnemonic for automatic guidance source selection, 1 for automatic, 0 for manual
AWJSRA	Augmentor Wing Jet STOL Research Airplane
B	Backside mode
BLC	Boundary layer control
BRG	Bearing
C	Cruise
CDI	Course deviation indicator
CRS	Course
CRT	Cathode ray tube
DHT	Keyboard mnemonic for decision height
DLC	Direct lift control
DME	Distance measuring equipment
DR	Dead reckoning
EADI	Electronic attitude director indicator
F	Frontside mode
FD1	Flight director selector
FMA	Flight mode annunciator
FPA	Flight path angle
FP 1, 2, 3 or 4	Flight path selectors on the MFDCP
FR	Flight reference
G/A	Go-around

G/S	Glideslope
HDG	Heading
HSI	Horizontal situation indicator
HUD	Head-up display
IFR	Instrument flight rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
INS	Inertial navigation system
LAT NAV	Lateral navigation
M	Manual mode
MFD	Multifunction display
MFDCP	Multifunction display control panel
MLS	Microwave landing system
msl	Mean sea level
MSP	Mode select panel
NALF	Navy auxiliary landing field
NAV START	Navigation start
0	All SCAS modes off-flight director only
QSRA	Quiet Short-Haul Research Airplane
RPM	Revolutions per minute
SAS	Stability augmentation system
SCAS	Stability and command augmentation system
SDN	Strapdown (vertical) gyros
SEL	Select
SPD CONF	Speed configuration (function of flaps)
SPD PROF	Speed profile (computed or stored speed reference)
STBY	Stand-by
STOL	Short takeoff and landing
TAC	TACAN
TRAJ GEN	Trajectory generate
USB	Upper surface blowing flaps
VDI	Vertical deviation indicator

VERT NAV	Vertical navigation
VHF	Very high frequency
VOR	Very high frequency omni range
WAYPT or WPT	Waypoint
WCR	Critical waypoint
WPF	Keyboard mnemonic for final waypoint
3D	Three dimensional
4D	Four dimensional

Keyboard and Flight Mode Annunciator Mnemonics

ALT	Altitude
ANAV	Area navigation
ATN	Keyboard mnemonic for automatic guidance source selection, 1 for automatic, 0 for manual
DHT	Keyboard mnemonic for decision height
ESM	EADI safety margin symbol selector, 1 visible, 0 omitted
FPA	Flight path angle
G/A	Go-around
HDG	Heading
ILS	Instrument landing system
LAND	Land mode
LFP	Keyboard mnemonic for landing flap setting
MLS	Microwave landing system
SPD	Speed mode
TAC	TACAN
VOR	Very high frequency omni range

Flight Mode Annunciator Messages

SET USB TO 30^{o}	Enable automatic USB deployment.
DEAD RECKONING	
SET C POWER LVR	Set Mode C power-lever.
LOWER FLAP	
RAISE FLAP	
LIFT/DRAG IS ON	
CHECK NAVAID	
ENABLE ILS	
ILS INVALID	
ENABLE MLS	
MLS INVALID	
ARM MLS	
ARM ILS	
M/ILS NOT VALID	Neither MLS nor ILS is valid.
ANAV DISCONNECT	
NONFLYABLE PATH	

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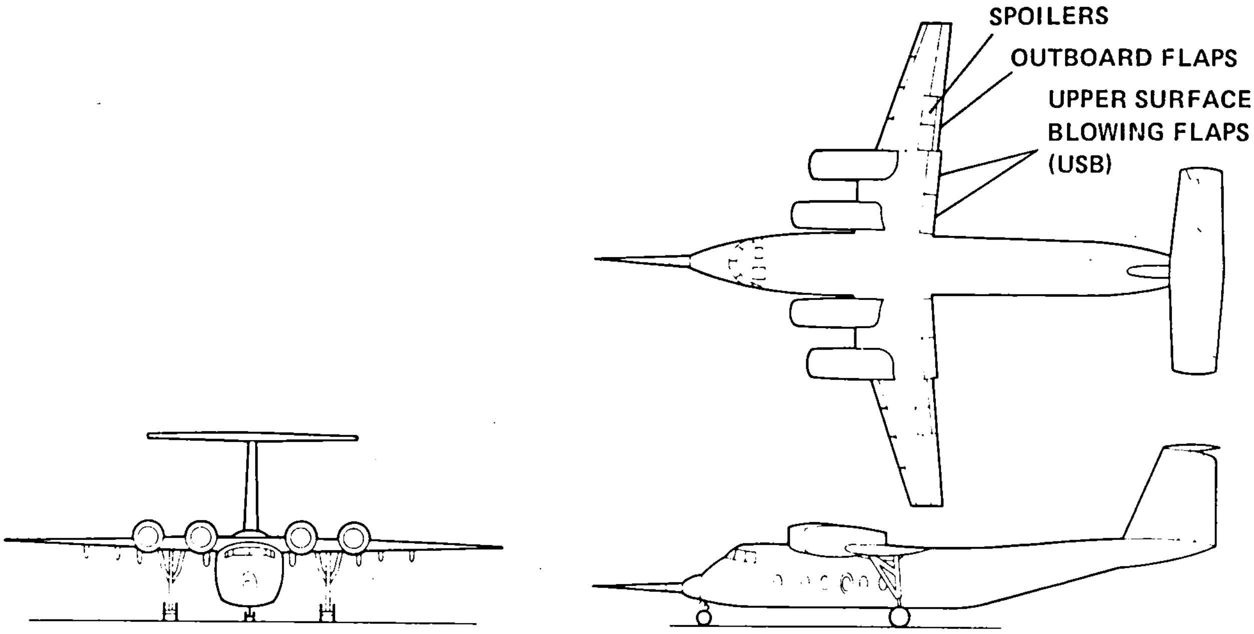
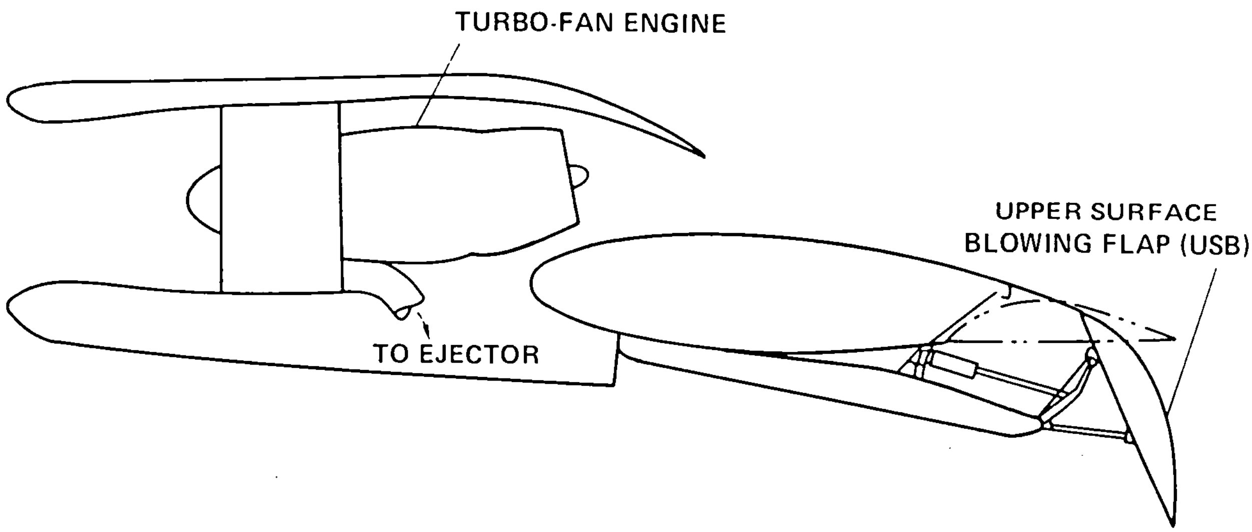
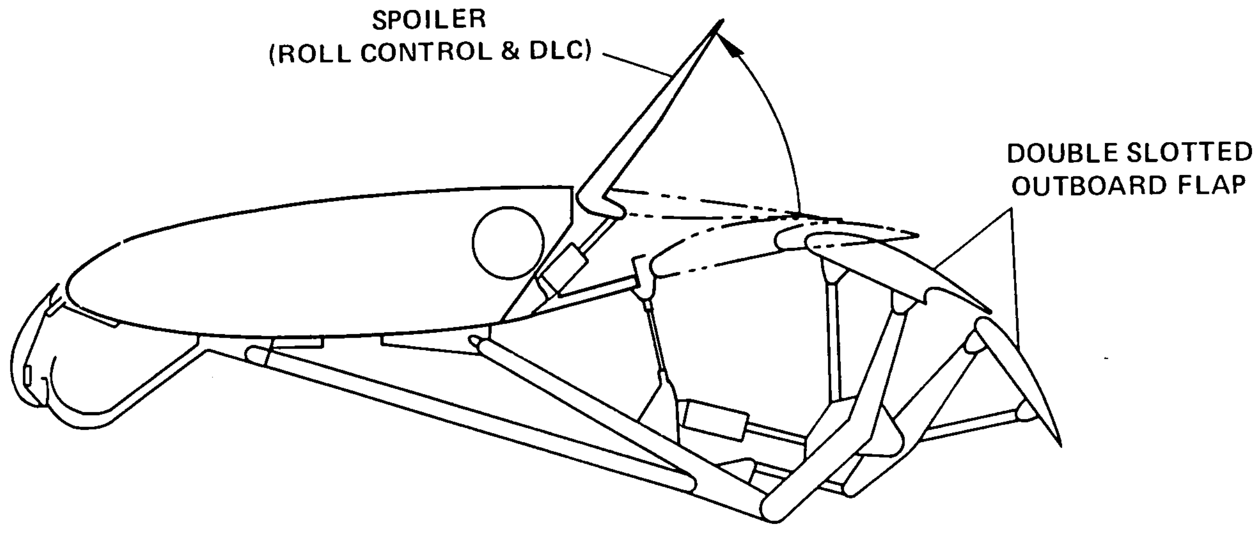


(a) General layout.

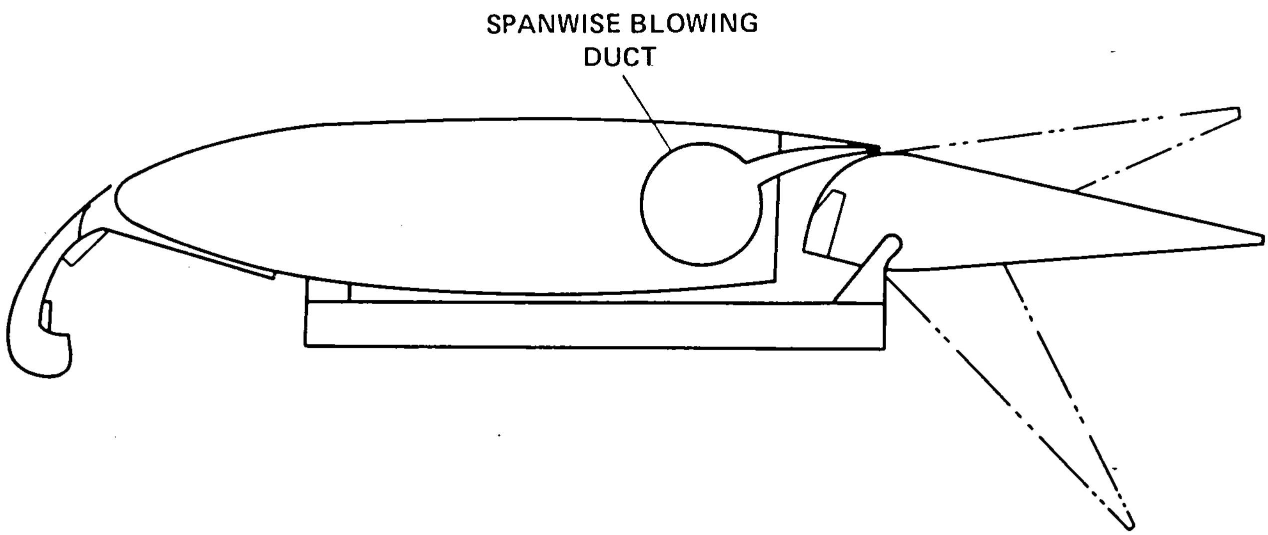


(b) Section through nacelle and USB flap.

Figure 1.- Quiet Short Haul Research Aircraft.



(c) Section through spoiler and outboard flap.



(d) Section through aileron.

Figure 1.- Concluded.

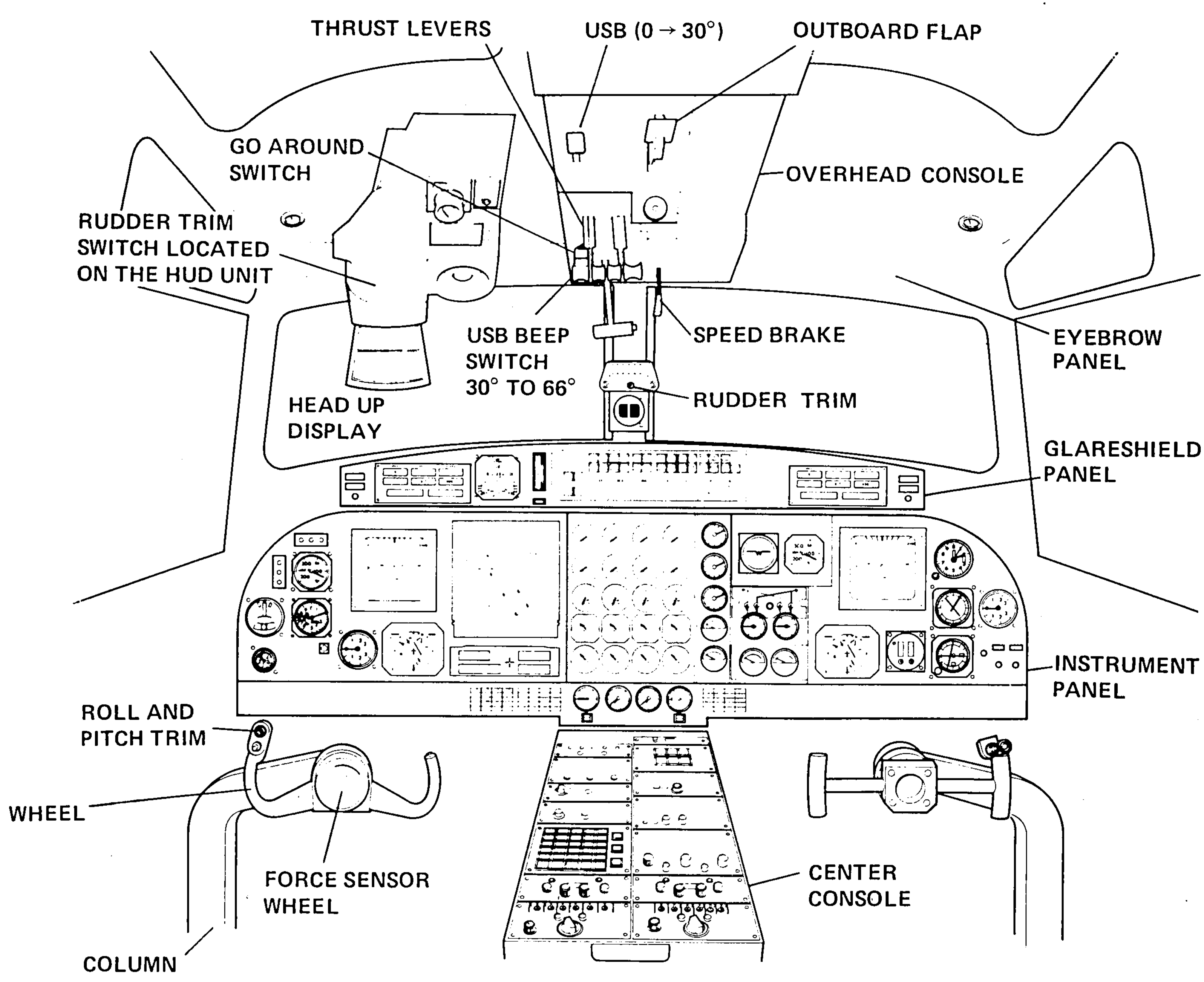
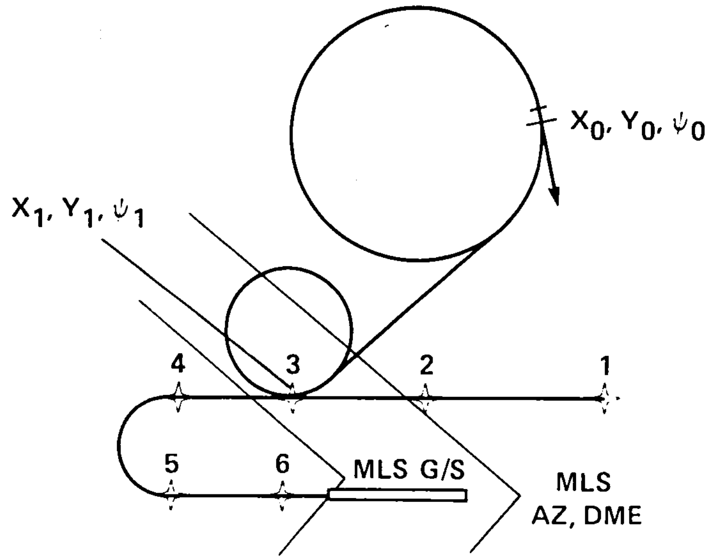
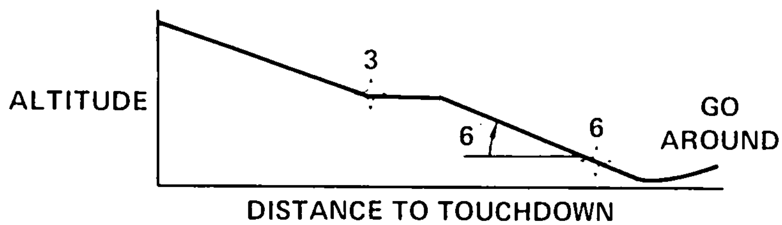


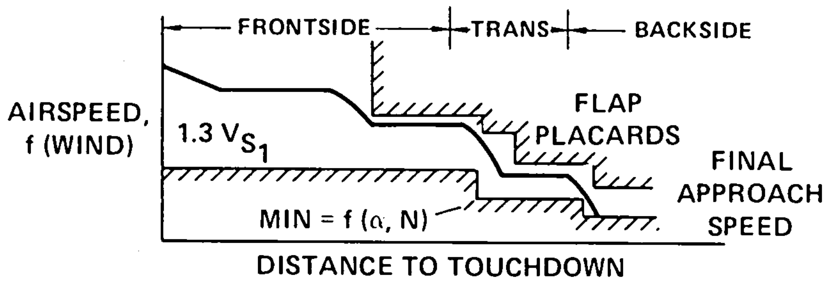
Figure 2.- Pilot and copilot controls for the QSRA.



SYNTHESIZED MINIMUM FUEL HORIZONTAL TRACK



SYNTHESIZED MINIMUM FUEL VERTICAL PATH



SYNTHESIZED SPEED PROFILE

Figure 3.- Synthesis of a fuel-optimal path.

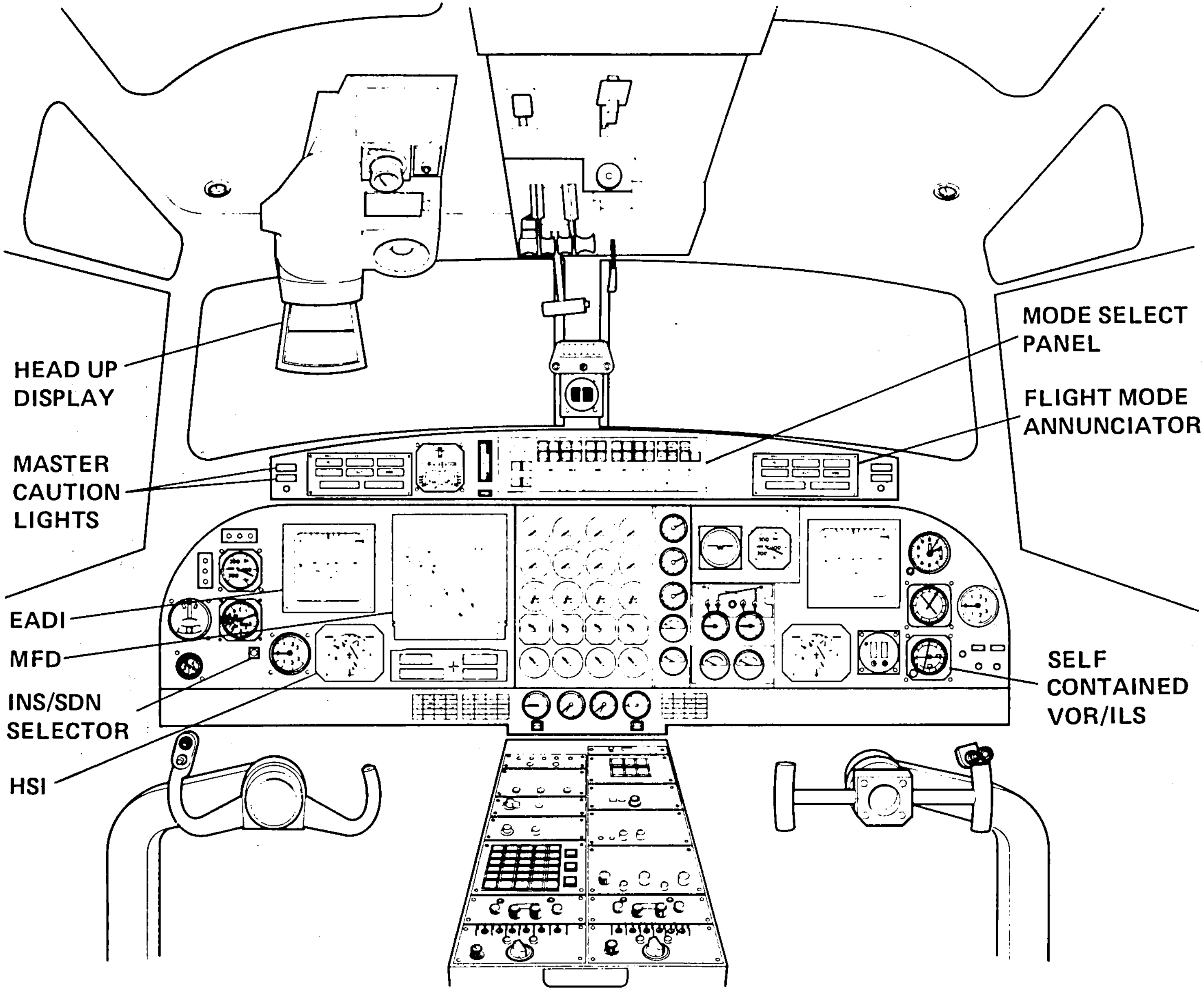


Figure 4.- QSRA cockpit layout.

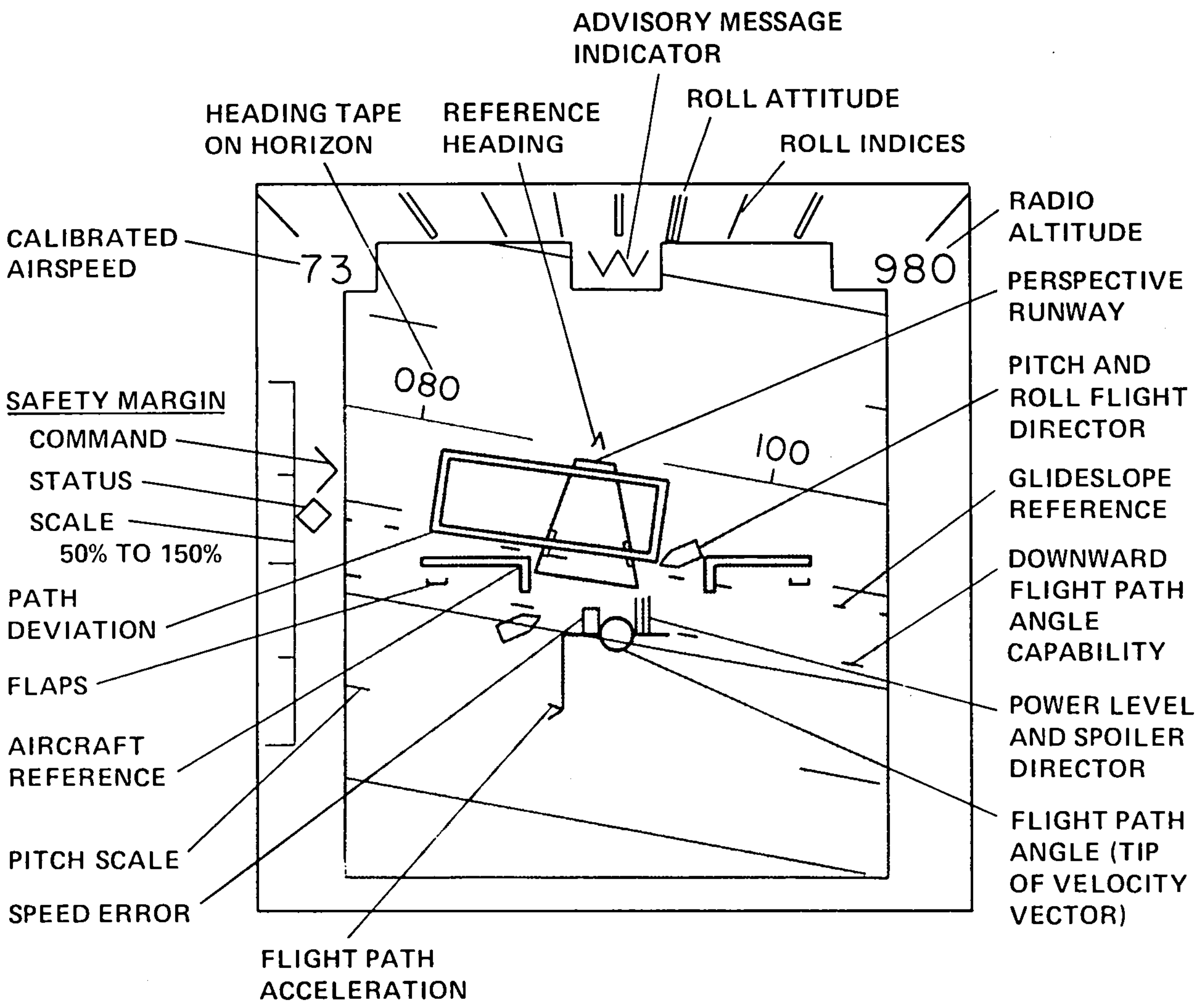


Figure 5.- Flight path oriented display format.

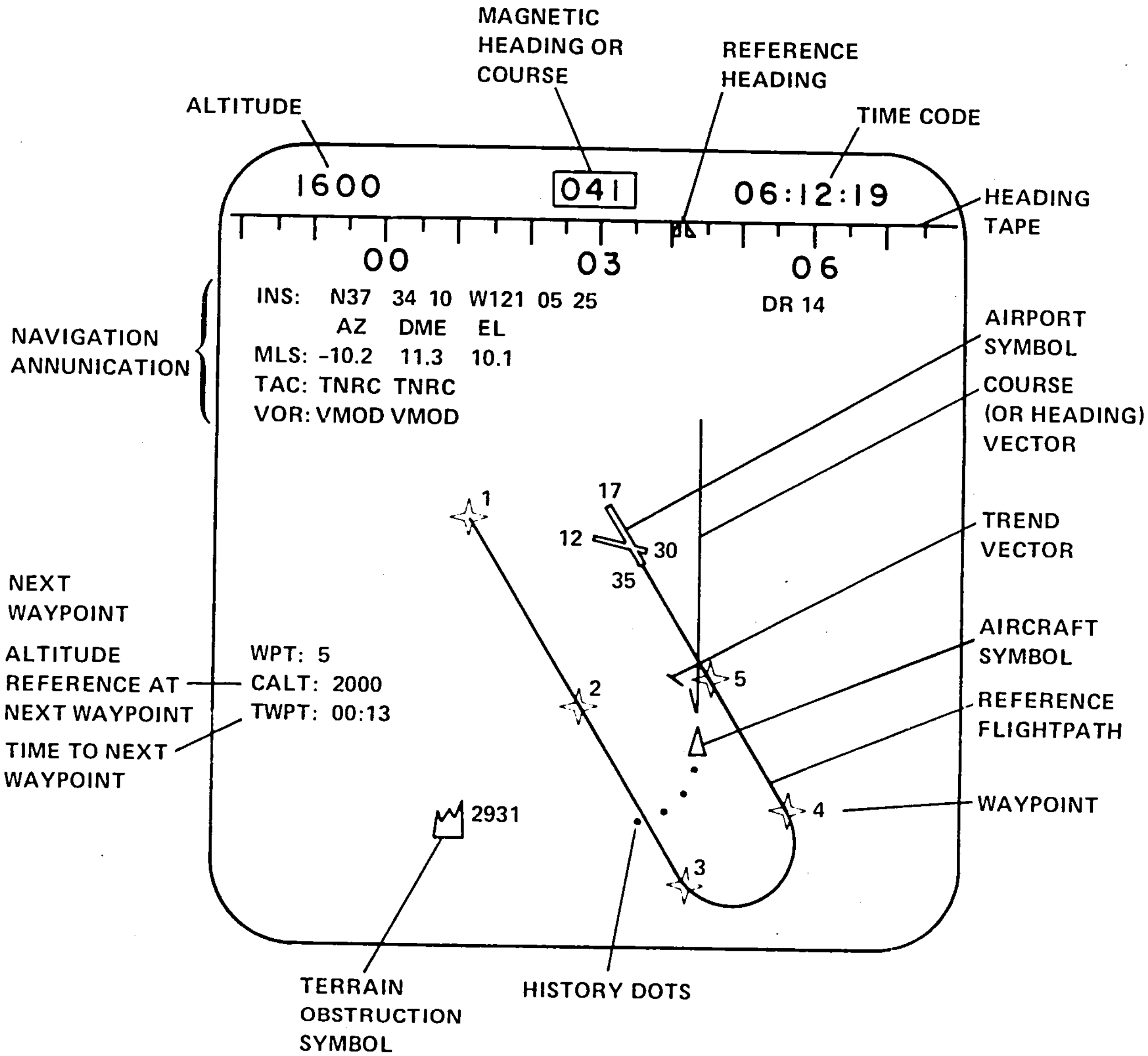


Figure 6.- Multifunction display.

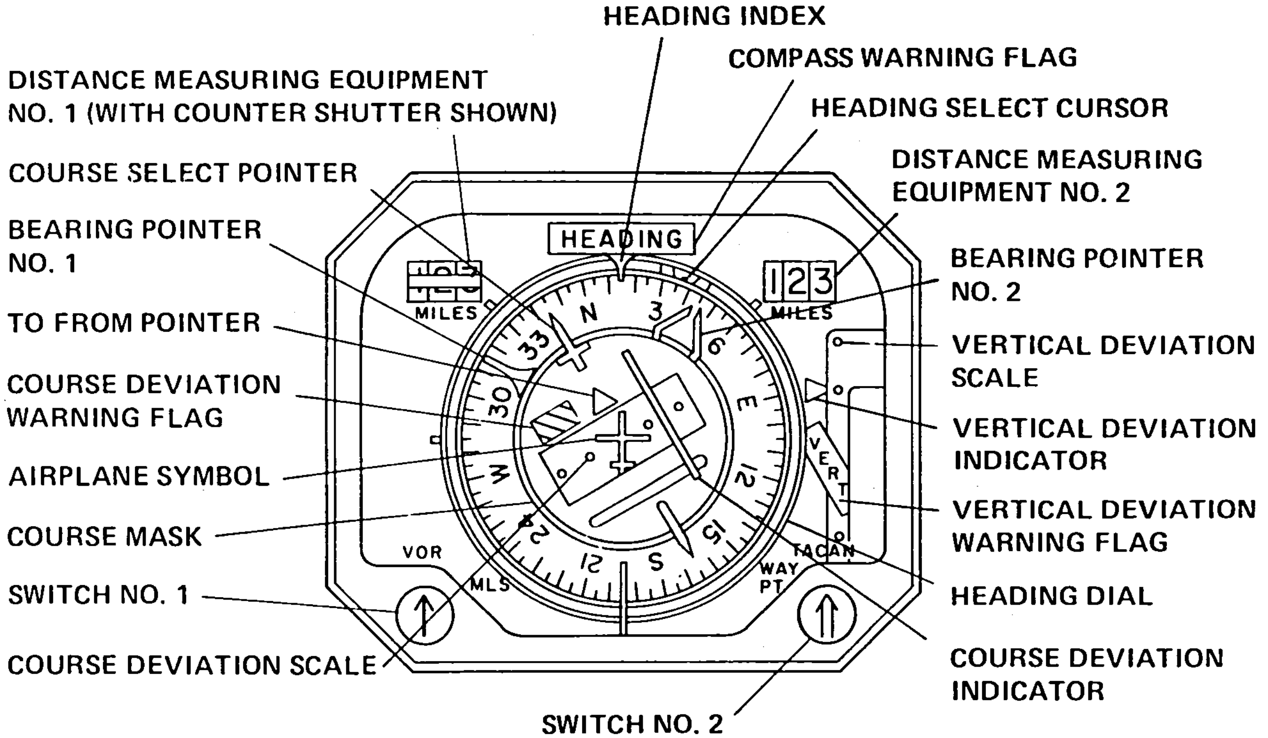
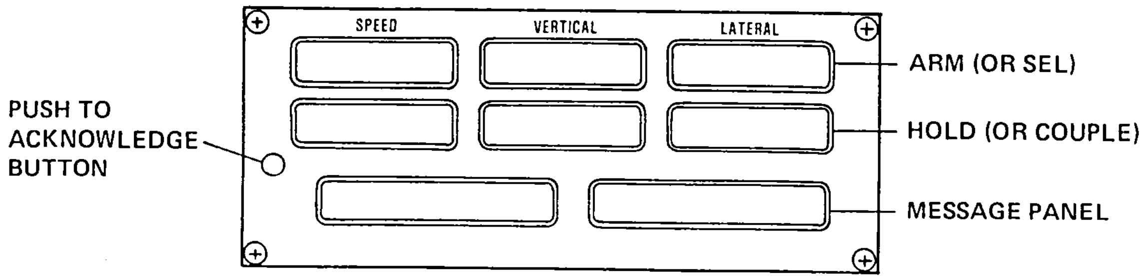
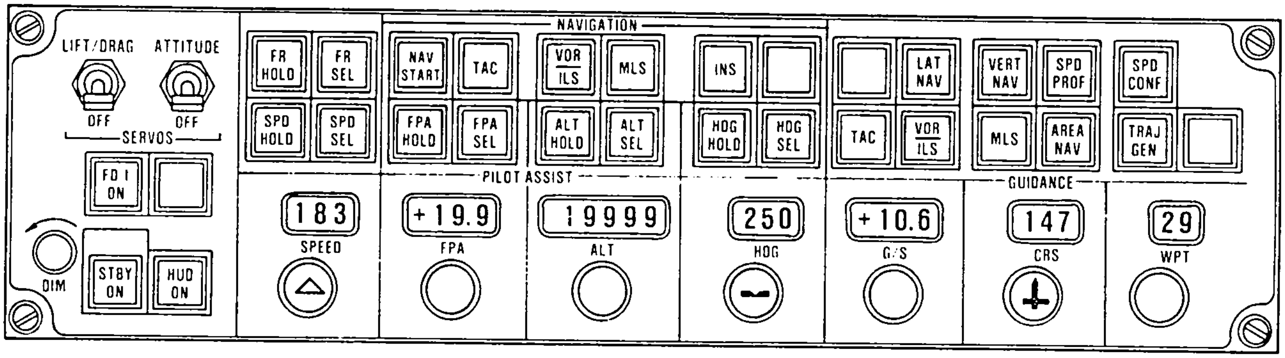


Figure 7.- Horizontal situation indicator (HSI) annotated view.



FLIGHT MODE ANNUNCIATION



MODE SELECT PANEL

Figure 8.- Mode select panel and flight mode annunciator layout.

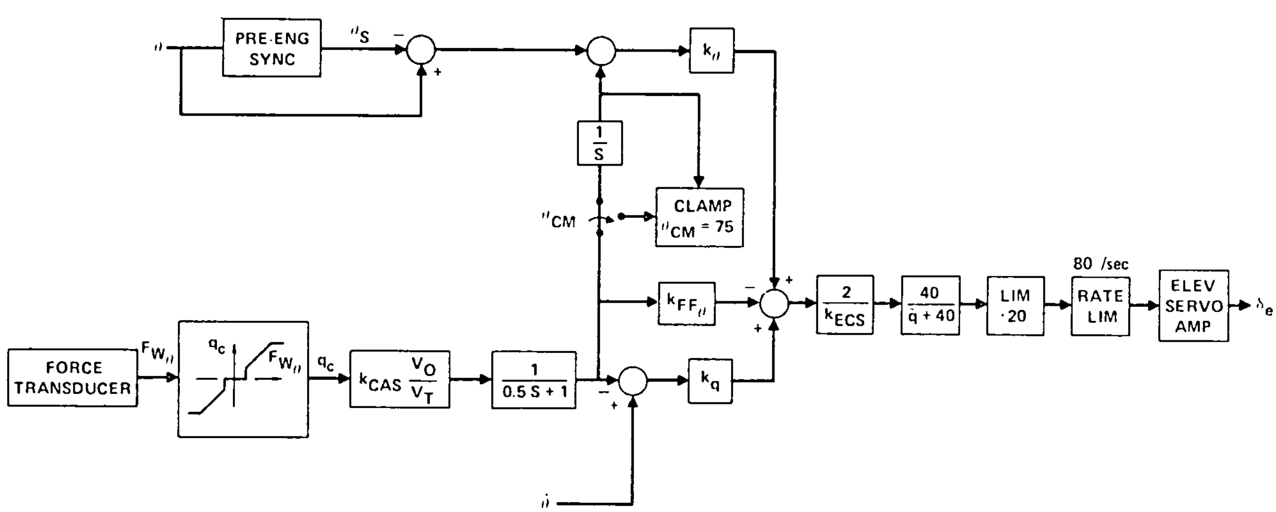


Figure 9.- Pitch stability augmentation system.

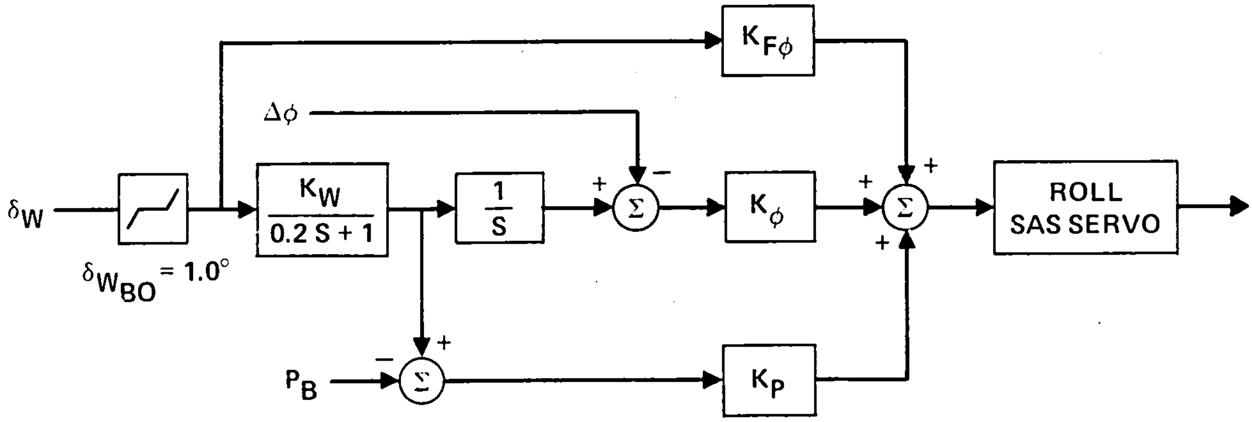


Figure 10.- Roll SAS.

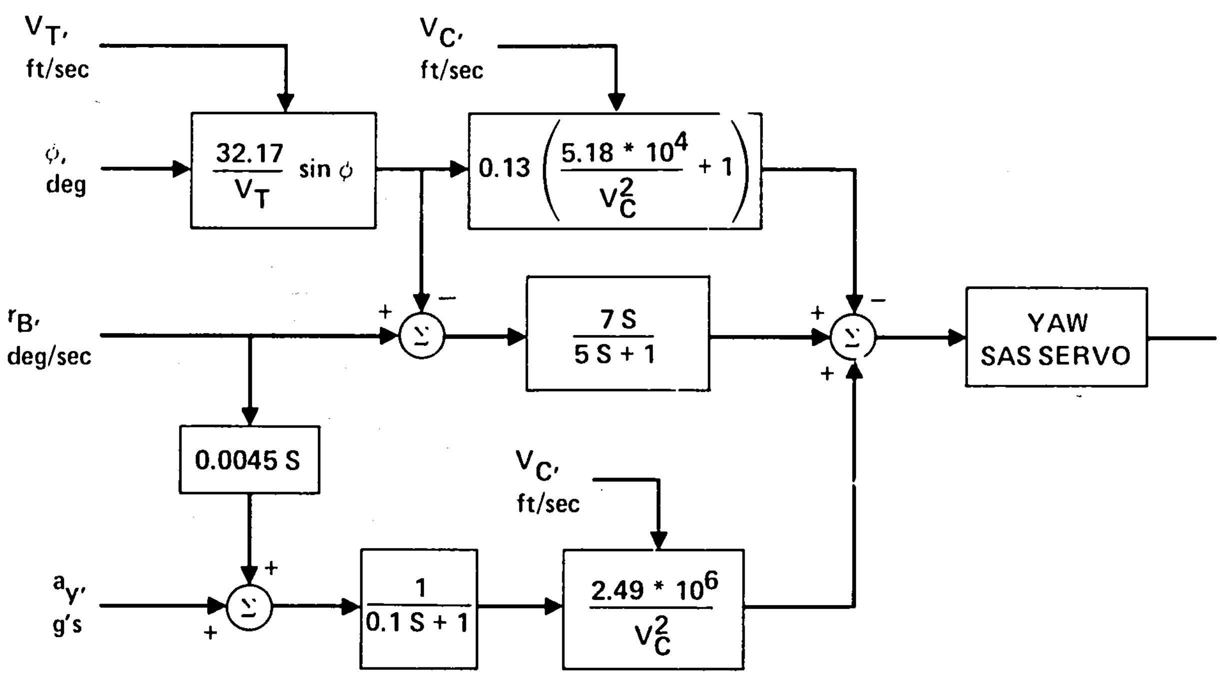


Figure 11.- Yaw SAS.

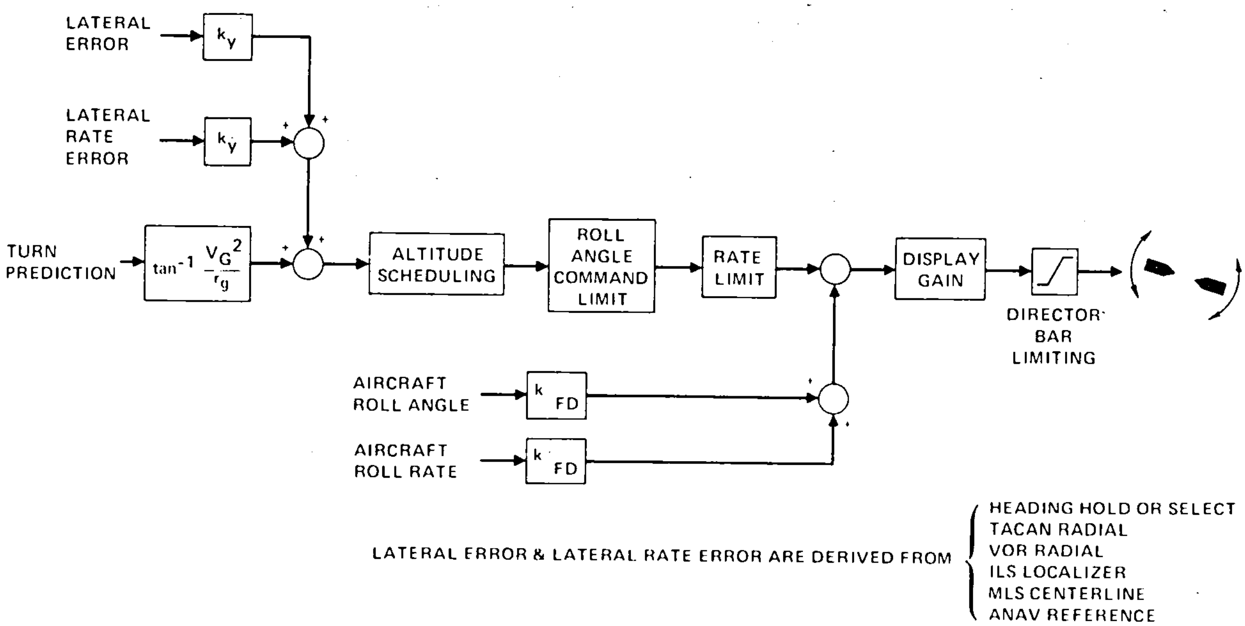


Figure 12.- Lateral flight director.

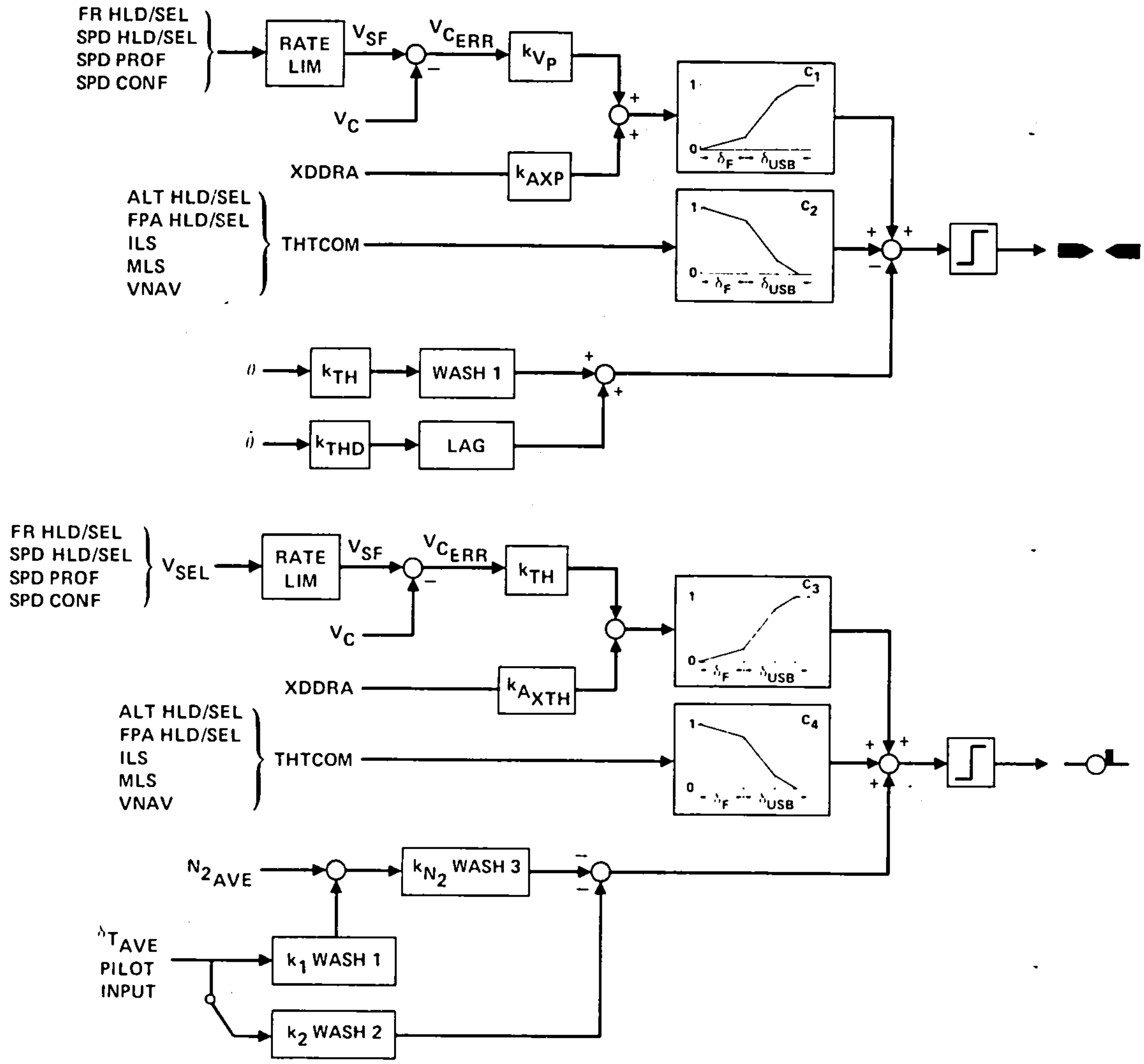


Figure 13.- Mode 0 (SCAS off) block diagram.

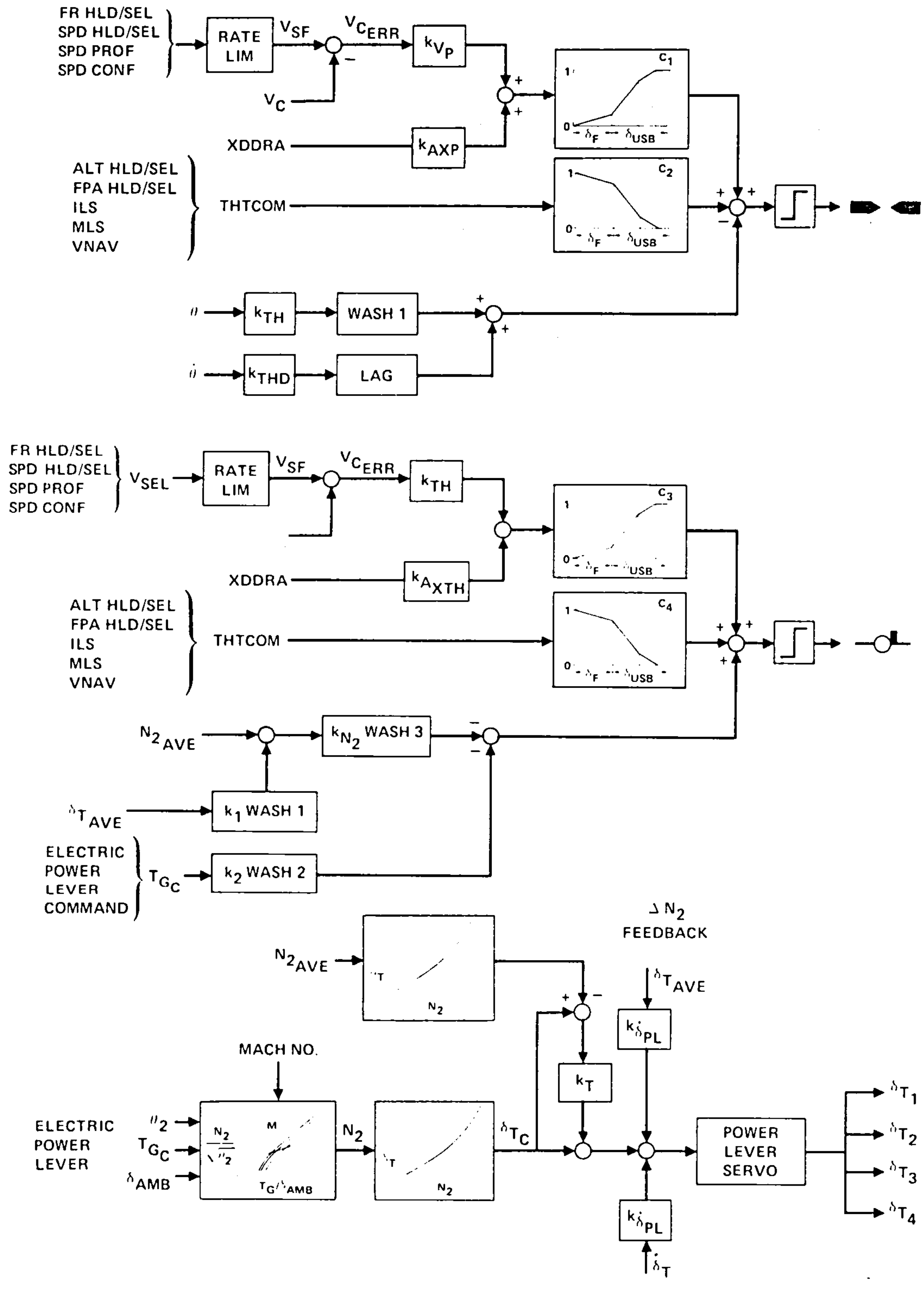


Figure 14.- Mode M (manual) block diagram.

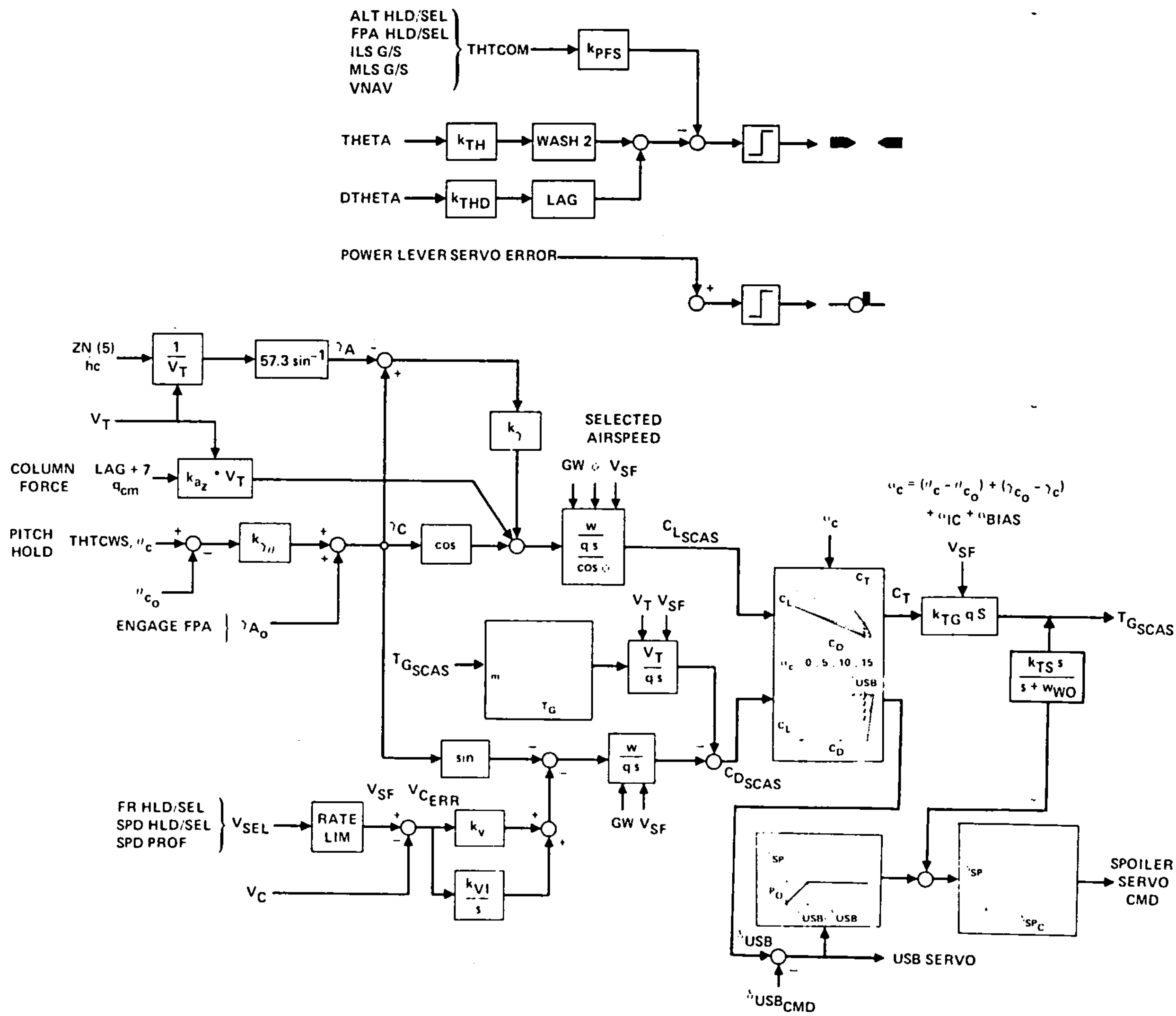


Figure 15.- Mode F (frontside) block diagram.

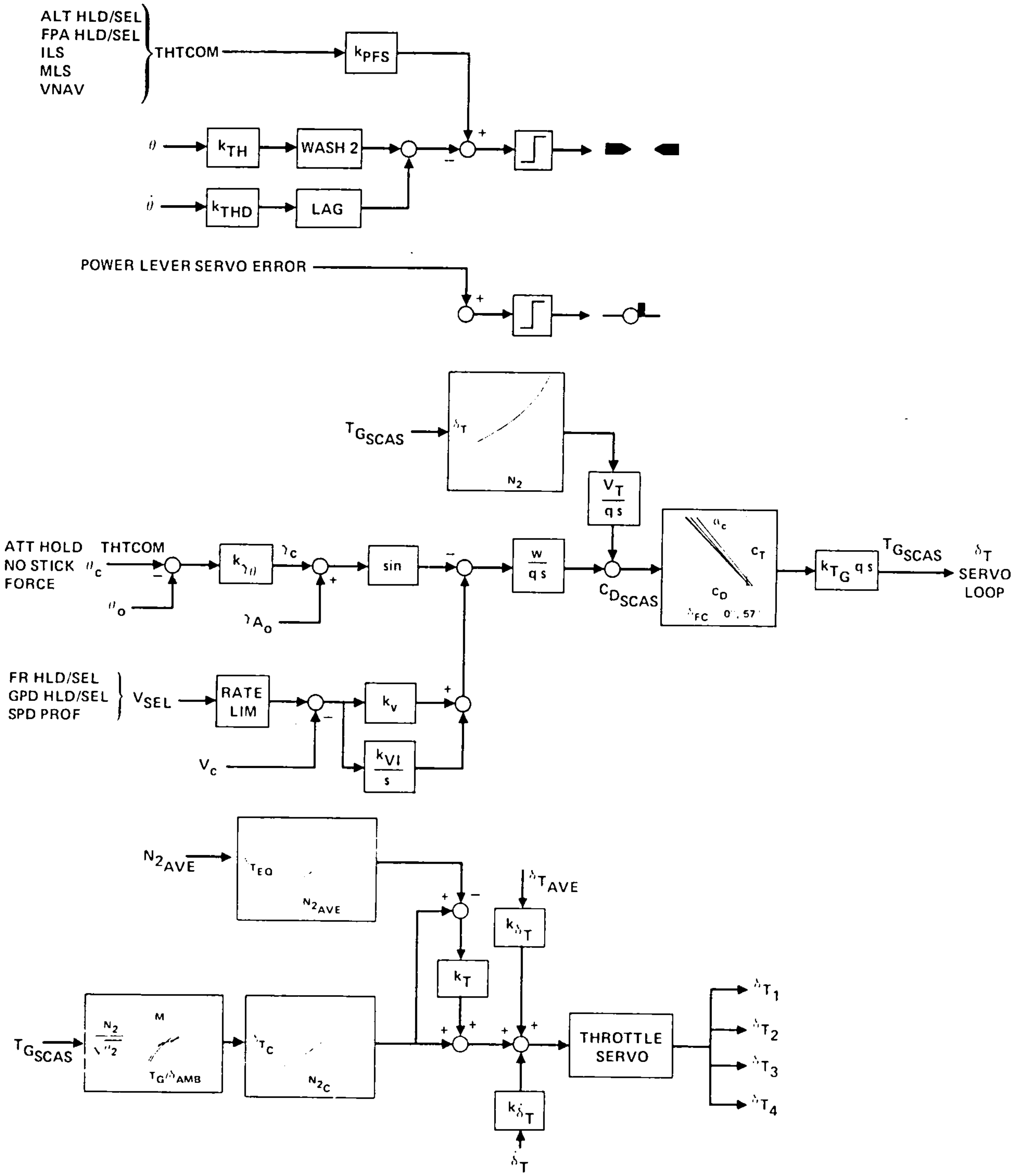


Figure 16.- Mode C (cruise) block diagram.

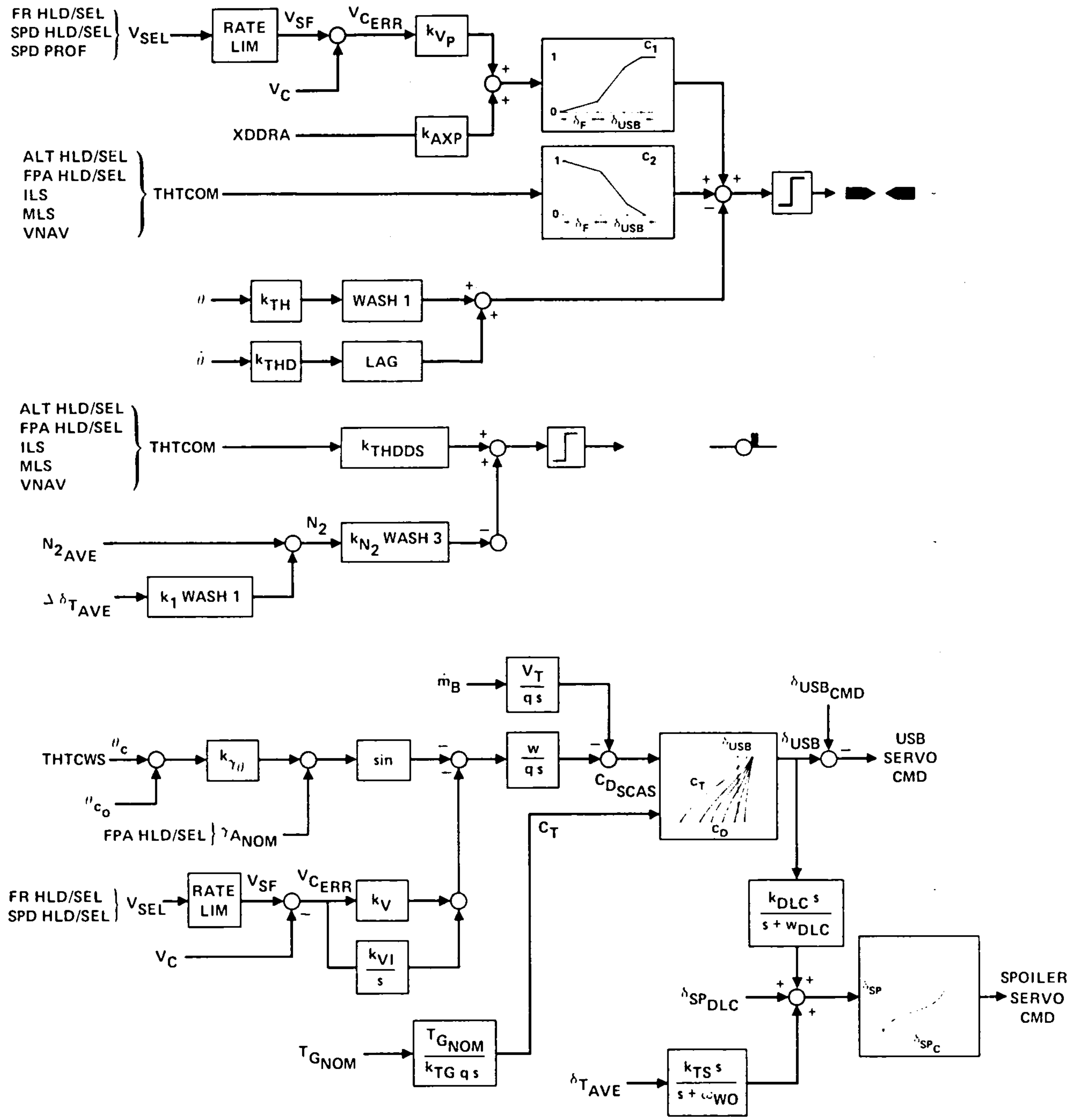


Figure 17.- Mode B (backside) block diagram.

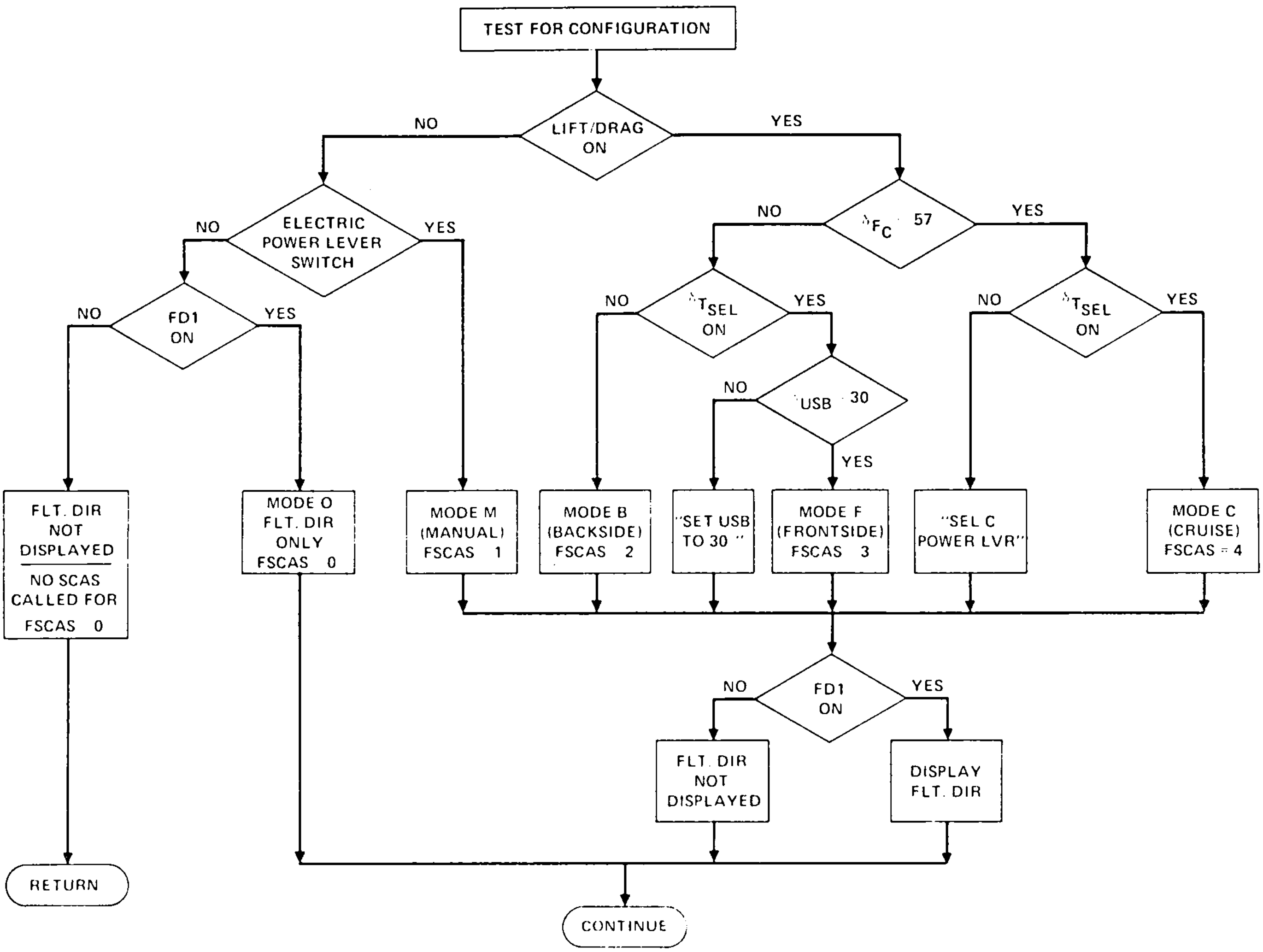


Figure 18.- Path-speed mode selection.

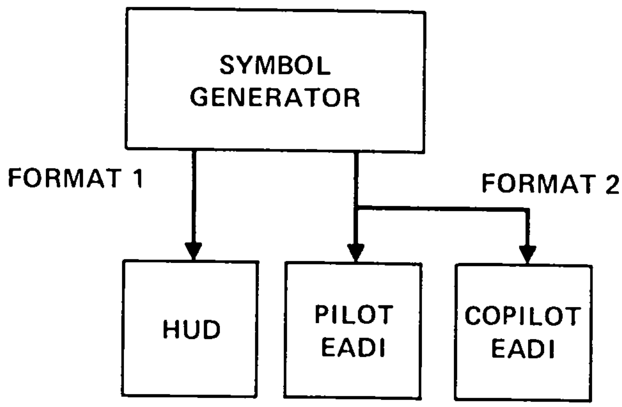


Figure 19.- Symbol generator drive capability.

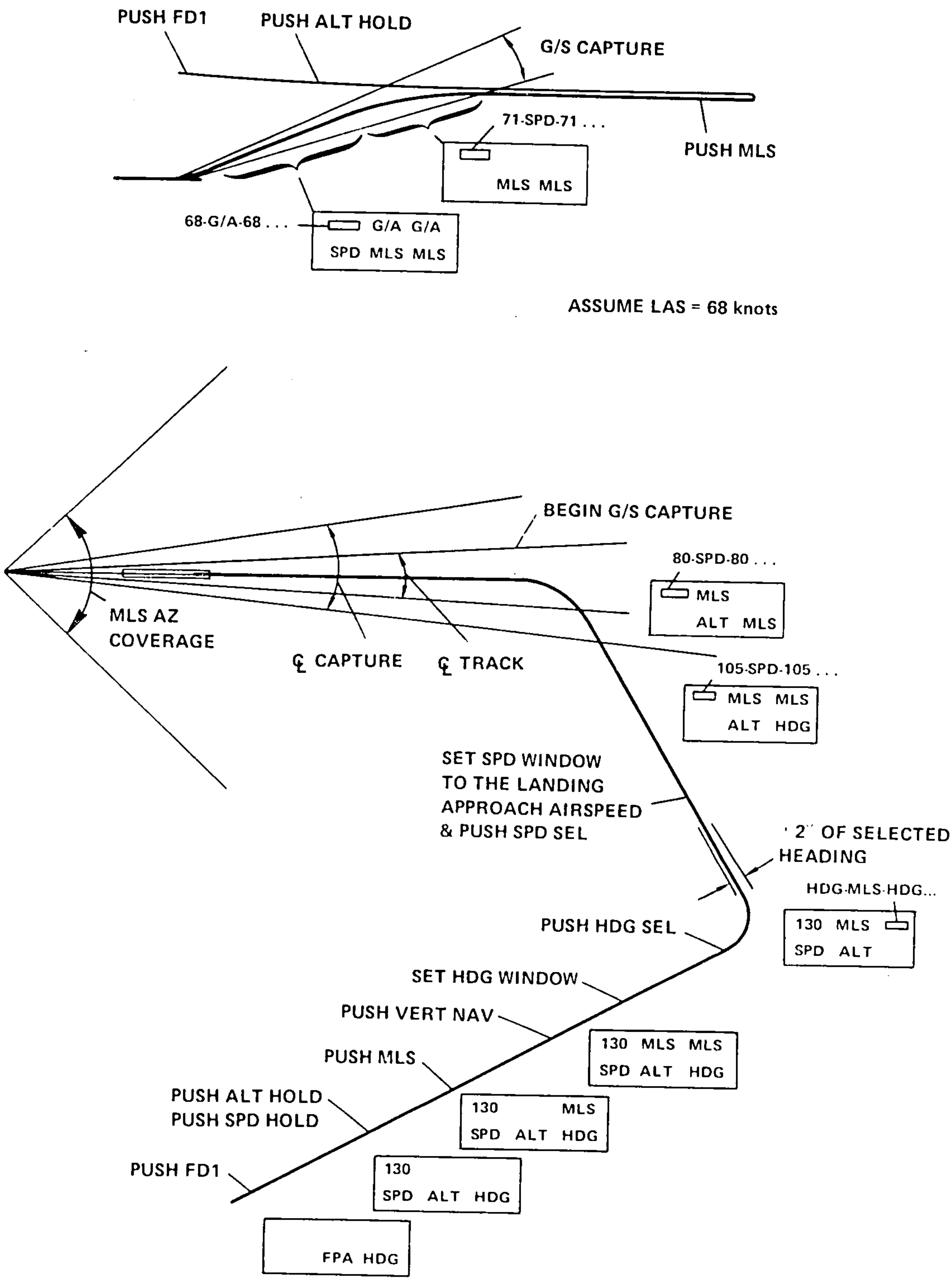


Figure 20.- Proceed to MLS track using ALT SEL and HDG SEL.

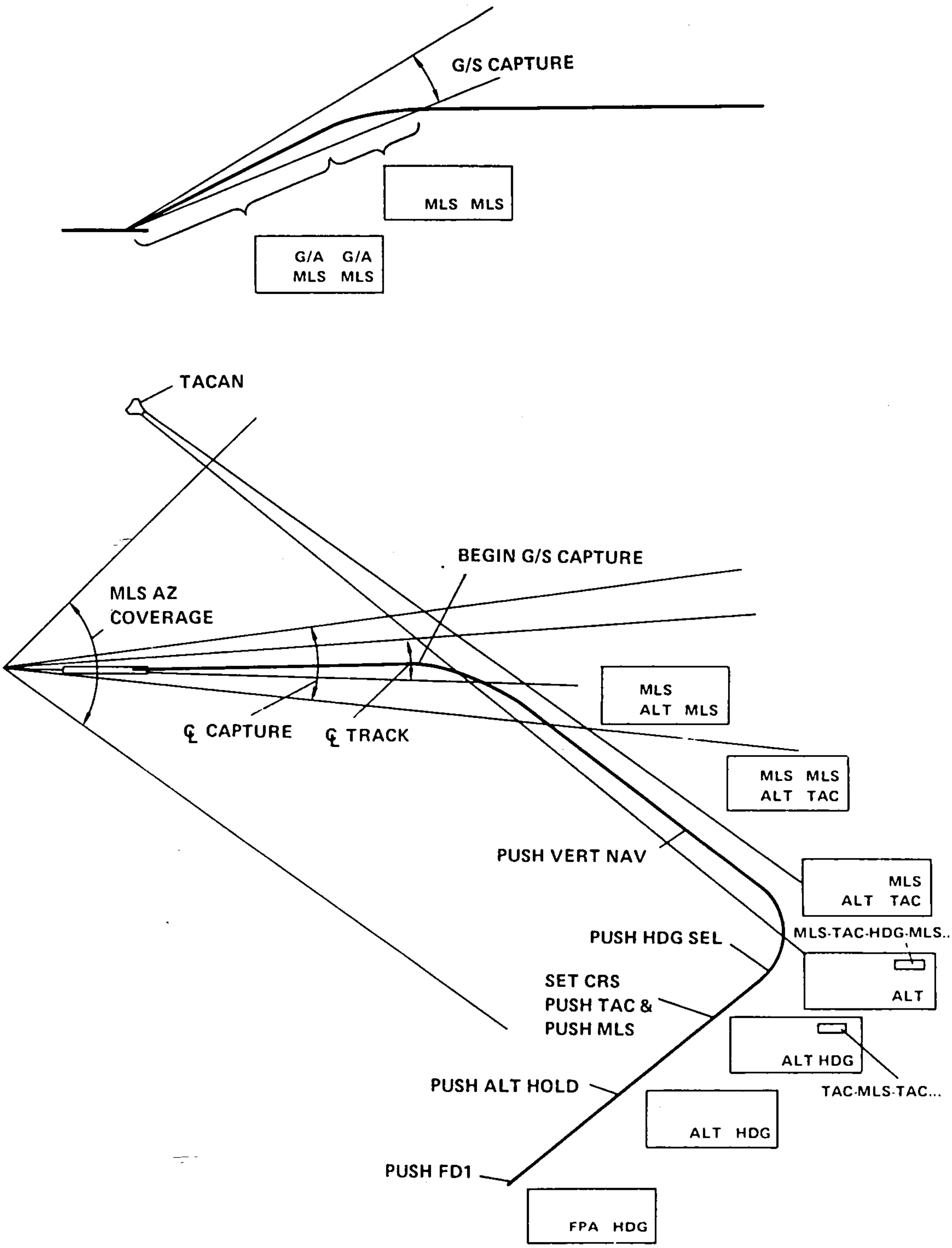


Figure 21.- Proceed to MLS track from ATL SEL and TACAN via HDG SEL.

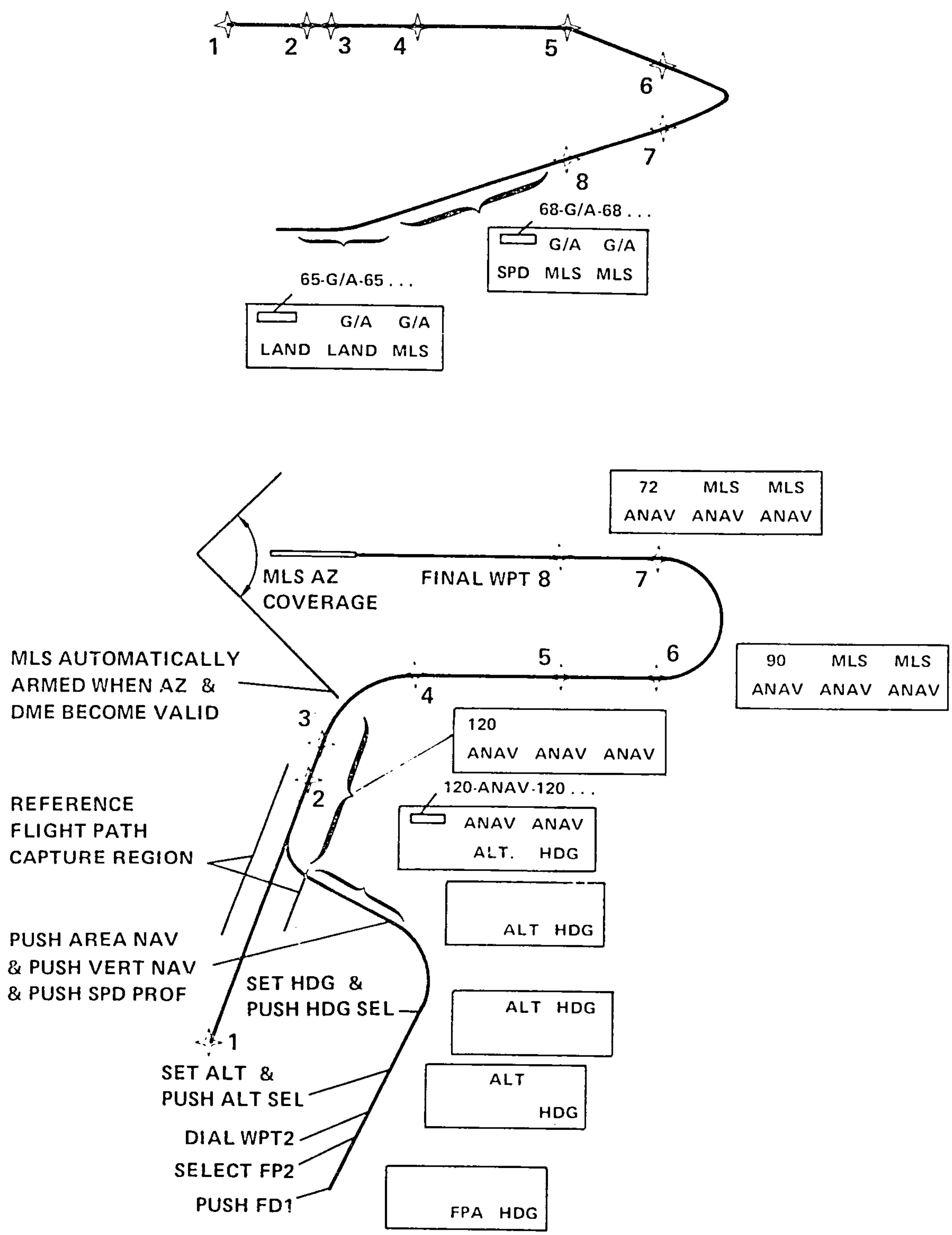


Figure 22.- Proceed to MLS track using Pilot Assist Modes to capture a reference flight path.

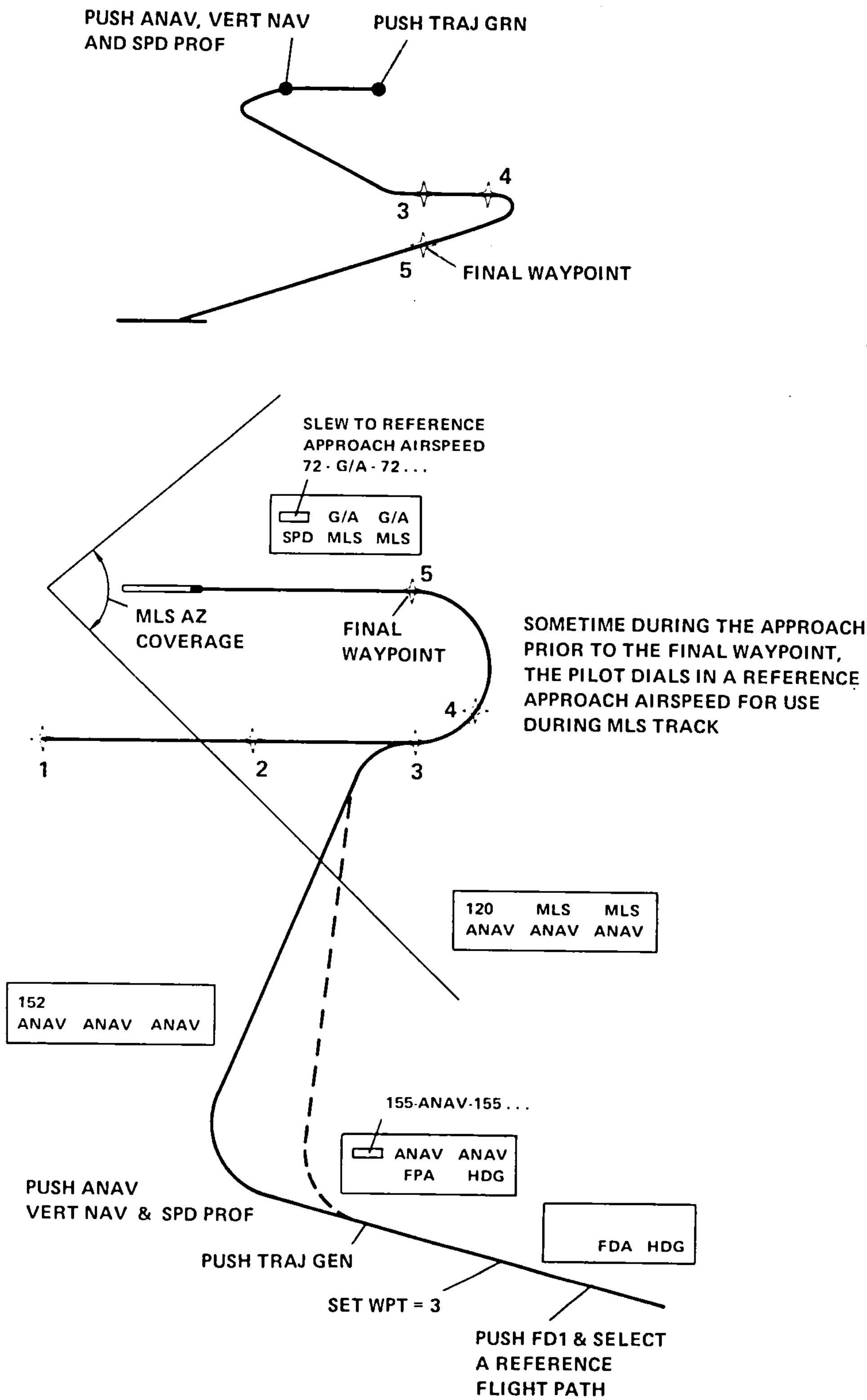


Figure 23.- Proceed to MLS from Trajectory Generate.

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15. Supplementary Notes

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16. Abstract

The planned operation of the mode select panel and flight mode annunciator for the digital flight control system to be installed in the Quiet Short-Haul Research Airplane (QSRA) is described. The QSRA, when equipped with programmable color cathode ray tube displays, a head-up display, a general purpose digital computer and a microwave landing system receiver, will provide a capability to do handling qualities studies and terminal area operating systems experiments as well as to enhance an experimenter's ability to obtain repeatable aircraft performance data. The operating systems experiments include the capability to generate minimum fuel approach and departure paths and to conduct precision approaches to a STOLport runway. The mode select panel is designed to provide both the flexibility needed for a variety of flight test experiments and the minimum workload operation required by pilots flying into congested terminal traffic areas.

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